# .....SANITARY LANDFILL DESIGN
# AND
# CONSTRUCTION

AREA WIDE
WASTE TREATMENT
208
MANAGEMENT

September 21, 1981

Long Island Regional Planning Board

# Seminar on Sanitary Landfill Design and Construction
## September 21, 1981

**Long Island Regional Planning Board**

Held at the Suffolk County Legislative Building
County Center, Veterans Memorial Highway
Hauppauge, New York

# Foreword

The Seminar on Sanitary Landfill Design and Construction took place under the auspices of the Long Island 208 Plan Implementation Program. This program is funded by the United States Environmental Protection Agency for the purpose of helping to carry out the recommendations of the Long Island 208 Areawide Waste Treatment Management Plan, July 1978.

Among a number of other tasks named in the program, the Long Island Regional Planning Board is required to run a series of workshops and seminars on topics related to Areawide Waste Treatment Management. The first in the series, 208/201 Workshop was held on March 31, 1980, and was attended by public officials and engineering consultants interested in the interrelationships between 208 Areawide Planning and 201 Facility Planning. No proceedings were issued. The second seminar, on the Protection of Groundwater from Toxic and Hazardous Materials, was held on November 17, 1981, for an audience including public officials, engineering consultants, and representatives of industry. The wide interest in the seminar made it necessary to publish proceedings.

The present seminar has also generated wide interest, and these proceedings are a response to that interest.

# Table of Contents

# Welcoming Remarks

## Legislator John J. Foley
### Suffolk County Legislature

*Good morning, engineers. I think that is a good generic term that avoids all the pitfalls of other problems. My name is John Foley. I happen to be one of the County legislators, and they pressed me into service this morning to say a word of welcome.*

*Some of you people in the room may recollect that you and I had our first encounter in connection with the landfill, or proposed landfill, in the South Setauket area of the Town of Brookhaven, at the abandoned sand mining operation there. Part of that process at that time resulted in a report known as the Baffa Report. That's possibly history; now, ancient history to some people.*

*There has been movement in that particular situation, but it does point up the fact that this is a very serious and basic problem that we have. Everybody here is involved, at varying levels, and to varying degrees. This problem is still with us, and I might simply say to this collection of intelligence, expertise and know-how or whatever words you want to apply, that legislators and county executives are responsible for making decisions, but they rely heavily upon the strength of you people individually and collectively. I would simply say to you, also, that, in a very real sense, we are at your mercy, because your strength, your integrity and your courage can determine the course of human events in the Town or County or State or nation itself. So, where it is necessary, I would hope that you will in the future, speak up and indicate where there are problems, where there are errors, where there should be corrections, and where people in the legislative or executive process may be in error. You and we are really involved in a process that relates to responsibility, and it's only through all of these factors that we can be assured that the rights and interests of people doing their jobs are protected. Since we are living in difficult times, and are faced with the environmental problems still remaining with us for 1982 and beyond, we all share responsibilities in these matters, regardless of our professions.*

*Some people might look down on professional politicians, but I have no objection to that particular label by any means. I as a legislator, and you as engineers, or as attorneys or whatever, you and I have an additional responsibility, not merely to be dedicated technicians in our own fields, but we also have the responsibility to draw in other disciplines as may be necessary to deal with all questions that bear on the public trust.*

*I thank you for this opportunity to say that to you. Some of my best friends are engineers. Thank you.*

# Opening Statement

## Dr. Edith Tanenbaum
Long Island Regional Planning Board

Legislator Foley, ladies and gentlemen, I'm Edith Tanenbaum of the Long Island Regional Planning Board staff. It's my pleasure to welcome you to the latest in our series of technical seminars dealing with engineering aspects of Long Island water-related concerns.

Today's topics can really be summarized in one sentence: How can Long Island, with an annual output of well over two million tons of solid waste, and as yet relatively few satisfactory alternatives for its safe disposal, make sure that the long-accepted practice of buryng in a sanitary landfill is truly a solution and not merely the transformation of a problem.

As a planner, I can remember a considerable literature extolling the virtues of sanitary landfills, the elimination of open burning and the reduction in odors, vermin and other nuisances. In fact, possession of a sanitary landfill was considered the hall mark of a modern municipality. Long Island was no less up to date than its neighbor to the west.

Today, Long Island has its landfills, including some forty major active and abandoned ones, and with them, landfill-related problems.

Excluding the fact that nearly all of the active landfills are at, or near, capacity, the most important problem is the generation of pollutant-laden leachate, which has adversely affected groundwater quality in the vicinity of landfills and down-gradient from the landfills.

The amount of leachate produced depends upon the area extent, volume, absorptive capacity and the amount of recharge water infiltrating the landfill. According to the reports on groundwater conditions prepared as part of the 208 Areawide Waste Water Management Plan, 100 acres of landfill can generate 40,000 gallons of leachate per year under climatic conditions similar to those of Long Island. The older landfills in the bi-county region typically range in size from twenty to sixty acres, usually located in mined-out sand or gravel pits and are unlined.

Many, if not most, landfills receive a wide variety of material, paper products, food wastes, septic tank sludge, construction debris, tires, cars, leaves, plastic, glass, chemicals, cans, oil and hydrocarbons, street and building sweepings, dead animal wastes, sewage and water treatment sludges.

The 208 study, concerned as it was with water quality, recommended the prohibition of new landfills, and the expansion of existing ones, within the deep flow recharge zones, where leachate could be expected to contaminate portions of the Magothy aquifer, the most important source of public water.

It recommended the imposition of strict controls over the establishment of new landfills on the north and south forks and the upgrading of existing ones, where feasible. New landfills were considered acceptable only in case of extreme hardship, and provided that extraordinary measures were taken to protect the ground and surface waters.

It further recommended that, in the remaining areas (the north and south shores, including the land around Great South Bay), new landfills should be permitted under current New York State policy, provided the sites were located landward of the primary coastal zone, and that there be an adequate depth to groundwater to insure an adequate unsaturated zone. The New York State Department of Environmental Conservation has accepted these recommendations and has made them part of the Region 1 Solid Waste Management policy.

A realistic appraisal of Long Island's current situation suggested the need for landfills for the disposal of substantial waste. With that in mind, the Long Island Regional Planning Board assembled a group of experts to tell us how to design and construct the kind of landfill we can live with. I believe you've all read copies of the program that were at the registration desk. I don't need to go over it with you, except to indicate that we have a very full program.

I am very happy that we were able to convince such a group of distinguished speakers to be with us.

# List of Figures

# List of Tables

# Natural Clay Liners - The Town of Babylon Landfill Experience

Dennis J. Lynch, Commissioner
Town of Babylon Dept. of Environmental Control

## Abstract

*The Town of Babylon sanitary landfill, an 82 acre site located in the southwest portion of Suffolk County, receives approximately 700-800 tons of residential and community solid waste daily. About 50 acres are designated for the deposition of solid waste; 10 acres are used for the acceptance, treatment and disposal of liquid waste. In 1980, an additional two-acre area adjacent to the landfill site was selected for expanding the solid waste disposal area. In compliance with New York State Solid Waste Management Policy concerning landfill expansions, the Town of Babylon was required to line the selected site and did so with natural clay. A 6" sub-base of sandy loam was placed over the site above which an 18" layer of natural clay was spread and compacted to 12". Above that, a final 12" layer of clay was spread and graded at a minimum slope of 0.5 percent to direct leachate toward perforated concrete pipes along the periphery of the site. Two 3,000 gal. impermeable concrete tanks were connected to the pipes to collect and store leachate. The total project cost was determined to be $75,000 per acre; construction time was one and a half months. To date, less than 50 percent of the anticipated 3,000 gal. of leachate per week has been collected via the drainage system into the storage tanks. With respect to local groundwater flow and geology, future cost/benefit and efficacy, it is questionable whether further lining of the solid waste disposal area at Babylon is advantageous. Alternative actions, including capping and covering filled sites, installing methane collection systems and replacing contaminated private wells with a public water supply, should be explored.*

The Town of Babylon sanitary landfill is an eighty-two (82) acre site located in the southwest portion of Suffolk County. Since the mid-1940s, the Town of Babylon has disposed of residential and commercial solid waste, as well as scavenger waste from cesspools, at this location. At this time, the solid waste portion of the landfill occupies approximately fifty (50) acres, and another ten (10) acres are used for the acceptance, treatment and disposal of liquid waste. The Town of Babylon landfills approximately 700-800 tons of solid waste per day.

In late 1980, a two acre area in the northeast part of the landfill site was selected for expanding the solid waste disposal area. In order to comply with New York State Solid Waste Management Policy concerning landfill expansions, the Town of Babylon was required to line the two acre area, and decided to use natural clay for the purpose. It happened that the contractor who supplied cover material for the site, also had good quality clay available. The soil permeability of the clay material was measured and determined to be $10^{-6}$ centimeters per second. (The State requires a permeability not greater than $10^{-5}$ cm./sec.) Comments on the proposed plan of construction were solicited from the New York State Department of Environmental Conservation, and were found to be favorable.

Prior to commencement of construction, the site was filled in with acceptable sand and loamy material to bring the elevation to five feet above groundwater. Following site preparation, a 6" sub-base of sandy loam was placed over the two acre site. Eighteen inches of natural clay were compacted to a 12" thick clay barrier which was subsequently covered with a 12" final cover. The purpose of the sub-base and top cover was to protect the clay liner from puncture by any protruding objects above and below the liner. The selection of sandy loam material also served the practical purpose of accommodating heavy duty refuse trucks once the liner was in place. The liner and cover material was sloped at a minimum of 0.5 percent, to insure that the leachate generated would be directed toward collection pipes laid along the periphery of the project area. The collection system consisted of 12" diameter Class IV reinforced concrete pipe perforated on top and embedded in the liner such that a minimum of 12" of clay would be available underneath the pipe. Standard laying length was specified to be 4' and the strength requirements of the pipe met ASTM C-76 and C-655 standards. To insure resistance to corrosive attack by leachate, the pipe was coated with cold tar epoxy Bitumastic #300-M. To provide for water tightness at the joints, Ram-Neck flexible plastic gaskets were installed in

the field using the double gasket method. The flexible plastic gaskets met or exceeded the requirements of Federal specifications SS-S00210, Sealing Compound, preformed plastic for pipe joints, Type 1, Rope form. Approximately 650' of the Class IV concrete pipe was laid to complete this project.

The perforated concrete pipe was covered with ¾'' gravel prior to placement of the top cushion of sandy loam. The collection pipes were constructed to convey leachate to the northeast corner of the project area for discharge into two 3000 gal. storage tanks. Each tank was constructed of precast reinforced concrete with a minimum 28 day compressive strength of 4000 lbs. per square inch. The two leachate collection tanks were aged at least two weeks prior to shipment and cured sufficiently to meet specified strength requirements. Each tank had inside dimensions of 10' × 10' × 4' deep. The minimum thickness for the walls of each tank was 6'', and for the bottom slab, 9''. An 8'' thick cover slab was provided with each tank, capable of withstanding H-20 traffic loading. The precast concrete tanks were factory coated to insure water tightness. All interior surfaces, including the bottom slab, received two coats of **Rockweld C** waterproof coating. Manhole castings and frames were specified for each tank at 29'' in diameter. All exposed areas of the castings were carefully coated inside and out with black asphalt paint of approved quality. A locking device was also provided for each manhole to prevent unauthorized access to the tanks. Following the placement of the two tanks, and their connection to the leachate collection system, they were backfilled and the soil solidly compacted with mechanical tampers. The total project cost, which includes purchase of materials, equipment rental and in-house Town labor costs, was determined to be $75,000 per acre, installed. Construction time was one and a half months. The garbage pile over the lined area has attained a height of 85 feet during the 8 month period following construction. To date, it is estimated that less than 50% of the anticipated volume of 3,000 gallons per week of leachate generated has been collected in the collection tanks. Two possible explanations for this observation may be that (1) The filled capacity of the two acre site has not been exceeded to date, (2) The construction of a lined landfill adjacent to an existing landfill may result in the lateral movement of leachate through the 80 ft. high column of solid waste to a point which is outside the clay liner.

An important consideration with respect to the use of liners is whether they are necessary at all, at this particular location on Long Island. The Town of Babylon landfill site is located in hydrogeologic zone VII. Groundwater flow in this area is horizontal and therefore leachate generated may be expected to flow laterally in a south/southeasterly direction toward the Great South Bay. This fact was verified during the 1970s when the U.S. Geological Survey determined that a continuous layer of Gardiners clay underlies the entire site at a depth of approximately 100 ft. In effect, leachate generated at this point is effectively prohibited from impacting public water wells presently drawing water from the Magothy aquifer. Another important consideration with respect to the further expansion of the Babylon landfill site focuses on the future cost/benefit of additional lining. It is estimated that with the present two acre liner included, further lining of the solid waste disposal area at Babylon would result in a cost of nearly $1,000,000 to line approximately 15% of the total landfill area.

Since the mid-1970s, the Town of Babylon has provided public water mains and hookups for those households whose private wells are found to be contaminated with organic and inorganic chemical pollutants. This hookup program will be completed during 1983, and all contaminated private wells, not only those immediately adjacent to the landfill but throughout the Town of Babylon, will be replaced by the public water supply.

In view of the Town's commitment to provide public water for owners of chemically polluted private wells, and in view of the questionable cost effectivness and efficacy of lining at the Town of Babylon landfill site, it would appear that any additional funds to protect the groundwater should be directed towards alternatives other than the construction of an additional liner. These alternatives include the application of final capping and cover material upon landfill closure and the installation of a methane collection system. The Town of Babylon also suggests that an additional alternative to future landfill lining would be the replacement of contaminated private wells by public water supply.

# Bentonite as a Soil Sealant for Leachate Control in Sanitary Landfills

Henry G. Salomon

L.A. Salomon & Bro., Inc., Port Washington, N.Y.

## Abstract

*Bentonite, a natural clay product of volcanic origin, can be applied as an effective soil sealant for leachate control in sanitary landfills. Sodium bentonite is a hydrous aluminum silicate whose unique chemical arrangement permits a swelling of 10-15 times its dry volume when wetted. Besides absorbing large quantities of water, sodium bentonite can break down into colloidal particles much smaller than 0.5 microns. These properties of water absorption and breakdown into colloids enable bentonite to fill voids in soil, thereby creating impermeable barriers. The development of a series of contaminant-resistant bentonites has greatly enhanced the usefulness of these products for lining sanitary landfills. With contaminant resistant sodium bentonites, a permeability of $1.0 \times 10^{-7}$ cm/sec, or 79 gal. water/acre/day, can be achieved easily. Four steps are involved in establishing a bentonite landfill liner: (1) the soil is wetted to effect a 15 percent moisture content; (2) bentonite is applied first to slopes and vertical surfaces, next to horizontal surfaces; (3) bentonite is mixed into soil and finally (4) the entire area is compacted. Although contaminant-resistant bentonites must be used beneath a landfill and in slurry trenching bordering a landfill, they are not required in creating a cap above a landfill; for that, high yield bentonites would suffice. In colloidal state, bentonite is the only type of liner that reseals itself.*

My discussion will be on bentonite as a soil sealant for leachate control in sanitary landfills.

Bentonite, as most of you know, is a natural product of volcanic origin. It has been altered over millions of years into a clay. It is a special form of a mineral called montmorillonite. For those of you interested, montmorillonite gets its name because it was first discovered in a town in France called Montmorillon.

Chemically, bentonite is a hydrous aluminum silicate. This is true both of calcium and sodium bentonites; however, our interest is in sodium bentonite because of the extraordinary swelling properties caused by ion exchange reactions. Whenever magnesium replaces aluminum, which is offset by chemical ions attaching at the point of unbalance, this is known as base exchange or ion exchanges. While all clays are hydrous aluminum silicates, bentonite differs from other clays in that its chemical elements are arranged like a deck of cards. Between the so-called cards, consisting of plates of silica, and alumina, there are exchangeable ions, in this case sodium.

The exchangeable ions of a bentonite determine the thickness of the water film held by the bentonite cells. When the exchangeable ions are mostly sodium, the bound water film is thicker and held strongly by the bentonite cells. When the exchangeable ions are chiefly calcium, the bound water is thinner and more weakly held by the cells. It is for this reason that we're interested in sodium, because sodium bentonite in this reaction swells ten to fifteen times its dry size when wetted.

Water-dispersed Western sodium bentonite, besides absorbing large quantities of water, breaks down into colloidal size, 80 to 90 percent finer than one-half micron. It is this combination of swelling and breakdown into colloidal particles which causes bentonite to fill voids in soil, thus creating impermeable barriers. These may be essentially horizontal when bentonite is used as a liner, or vertical when applied as a slurry trench or cutoff wall.

We're extremely fortunate in that the world's best sodium bentonite comes from the four states of Montana, Wyoming, North Dakota and South Dakota,

with all major producers of sodium bentonites having their deposits in those areas.

As mined, bentonite contains about 40 percent moisture. Basic processing consists of drying and grinding into a powdered or granular product. Using a term common in oil well drilling, a good sodium bentonite has a ninety-barrel yield. Additional processing, generally using polymers, can increase the yield to 180 barrels or even better, greatly reducing the tonnage required to effect desired results, which is, of course, a very important economical factor with the high cost of freight.

The swelling properties of untreated bentonite are reduced by wetting with water having high mineral content, such as acid or salt contamination. However, specially treated, contaminant resistant, bentonites are available, and this is a very important factor, of course, in the use of bentonite in landfills, et cetera.

The development of a series of contaminant resistant bentonites by American Colloid Company has greatly enhanced the usefulness of these products. While natural clays may be combinations of various types and contain nonclay fractions, the proper use of contaminant resistant bentonites assures the permanent sealing of industrial waste lagoons, landfills, tank farms and other projects in which liquid or solid contaminants may be placed.

With contaminant resistant sodium bentonites, it is easy to obtain a permeability of $1.0 \times 10^{-7}$ centimeters per second, or seventy-nine gallons of water per acre per day. It is not difficult to obtain permeabilities of $1.0 \times 10^{-8}$, or a mere 7.9 gallons of water per acre per day. Permeability can be measured in the laboratory with various types of equipment. Head effect may be simulated by applying pressure. Since the design of a landfill calls for perforated-type drainage systems, as we've just seen, the actual water head is generally small.

Let us now go into the field for practical application of bentonite. The product is shipped, generally in granular form, in bags or in bulk. Delivery may be by rail or by truck. If by rail, the bentonite can be shipped in bulk in a gravity hopper car, dropped into a truck, which has a spreader attachment attached to it, and thus delivered to the site and spread. Bagged delivery at site is generally palletized on a flatbed truck for ease of unloading.

Whether using bentonite to line a pond, lagoon, tank farm or landfill, the procedure is quite similar. Four basic steps are involved. In order to make soil compactible, it should contain about 15 percent moisture, which may require some wetting. A simple way of checking the required moisture is to squeeze some soil in one's fist. If moisture can be squeezed out, it is obviously too wet. If, on the other hand, it completely loses shape when the fist is opened, it is obviously too dry. If, when the fist is opened, it maintains its shape, it is compactible.

Now, the next step is to apply the bentonite, first on hills, berms or sides, and then on the bottom, usually only as much as can be spread, worked into the soil to a depth of three or more inches, as required, and compacted in one day or one work period. Whenever possible, mechanical equipment should be used to effect economy. Spreading bentonite over an entire area is definitely not advisable, as bentonite should be kept dry until it is spread and mixed into the soil.

For larger projects, machine spreading is recommended. In order to assure spreading the proper amount, a spreader may be run over a tarpaulin of a known dimension. Then simply by weighing the tarpaulin, one determines whether the proper amount is being applied.

A proper mixture with soil is important. Again, mechanical equipment is recommended for larger projects. On small projects, adequate mixing can be obtained by hand, or by using a small rototiller. Larger projects will require heavier equipment, such as diskers. Mixing is followed by compacting, and rollers of sizes suitable to the size of the project can be used.

In a few cases, the area may be very steep or may be at a corner. There, hand mixing is required, but as much as possible, one should, of course, use mechanical equipment.

As mentioned earlier, side slopes are done first and then the bottom. Although a mixed blanket of soil and bentonite, because of its thickness, is not likely to be broken, the addition of gravel or crushed stone cover gives further insurance against seal breakage.

Figures 1 and 2 show a finished lagoon before filling and after. Whether pond, lagoon, tank farm or landfill, the steps are essentially the same. If there are large stones, they must be raked out, but extremely fine, uniform soil is certainly not essential, as may be the case with other liners. It should be noted that contaminant resistant bentonites must be prehydrated with fresh water in order to be effective. After such contact with fresh water—a good rainfall may do it—the jacket of water surrounding the bentonite can be visualized to be encapsulated in such a fashion that the dissolved chemicals in the leachate cannot penetrate and make contact with the bentonite and thus work to deteriorate the swelling. While contaminant resistant bentonites must be used under a landfill and in slurry trenching around a landfill, they are not required in creating a cap or umbrella over a landfill. This can be done with very high yield, but not necessarily contaminant-resistant bentonite.
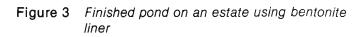
As was explained at the outset, bentonite was millenia in formation, alternately drying and wetting, a process which can continue indefinitely. As a matter of fact, it is extremely difficult to dry bentonite, especially when mixed with soil and covered. The resulting liner is as thick as the mixed blanket which has been created. In colloidal state, bentonite is the only type of liner which reseals itself. It may well be said that a bentonite liner is practical, permanent, economical and sometimes even beautiful. Figure 3 shows a liner used in a lake on an estate in East Hampton, and I think it is very beautiful.

4

**Figure 1**  *Finished lagoon before filling*



**Figure 2**  *Finished lagoon after filling*



**Figure 3**  *Finished pond on an estate using bentonite liner*

**Mr. Manning:** My name is Ron Manning from Brookhaven Hamlet. Has the maximum grade or slope that you can cover with bentonite been determined?

**Mr. Salomon:** It's been done on a one-on-one slope without any difficulty. Let me put it this way: The application of the bentonite does not change the character of the surface you're covering. In other words, if you have a slope which is holding as it is, the application of bentonite won't change that, because you only add enough bentonite to fill the voids in the soil. In fact, if you add too much, it doesn't add anything. That's why we usually try to get samples of soils, which are then tested by American Colloid Laboratories, and the recommended dosages are then figured out on that basis.

**Mr. Wolterding:** Dennis Wolterding, New York State DEC. For that project in East Hampton, what was the percent of bentonite used?

**Mr. Salomon:** That project was done a few years ago, and we used what is called SG 40. I believe that in that case they used about forty pounds per square foot, but now the same project would be done with very high yield bentonite, at one-and-a-half pounds per square foot.

**A Voice:** You didn't mention anything about cost. Can you give us an estimate, how much per square foot with contaminant resistant bentonite?

**Mr. Salomon:** For contaminant resistant bentonite, depending, of course, on the soil, the cost would be about forty or fifty cents per square foot, applied.

# Plastic Liners for Sanitary Landfills

Dr. Charles Staff

Staff Industries, Inc., Upper Montclair, New Jersey

*Abstract*

*The most commonly used plastic materials for sanitary landfill liners are **polyvinyl chloride** (in 20 and 30 mil. thickness, unreinforced), **chlorinated polyethylene** (30 mil. unreinforced) and reinforced **Hypalon** (36 mil.). These materials have a high degree of chemical resistance to inorganic compounds. However, different organic solvents have different effects on the aromatic hydrocarbons, chlorinated hydrocarbons and alcohols present in the various plastics. The chemical constitution of the proposed landfill material must be specified so that liner suppliers can recommend the best material for a given site. Liners are either placed as buried membranes or exposed membranes. Polyvinyl chloride is the preferred material for buried membranes because it has the lowest cost. Chlorinated polyethylene and, more commonly, Hypalon are placed as exposed membranes because they contain no volatile plasticizers. On average, plastic is $10^6$ times less permeable than clay. However, clay's liquid storage capacity is an advantage. The EPA has established that 10 feet of clay is equivalent to 20 mil. of plastic film. For on-site placement, sheets as large as 25,000 square feet are unfolded, spread, joined with resin solutions at seams and finally covered with a soil layer. Installation costs for polyvinyl chloride and Hypalon are $0.35 and $0.65 per square foot, respectively.*

I appreciate the opportunity of being here today. I'm sure you've all been hearing about plastic liners for all sorts of applications lately, reservoirs, ponds, canals, and many more, but we're interested here in this application for landfills.

Landfill liners are a small percentage of the market right now. The market is probably 500 acres per year, but the fraction in landfills is quite small.

Several years ago at a meeting on landfill liners in Vancouver, the subject of liner standards for landfills came up. The EPA was interested in it and was instrumental in getting a group together in Ann Arbor to talk about the matter. Subsequently, EPA published a booklet, SW 870, entitled **Liners for Waste Impoundment and Disposal Facilities,** based upon work done at the EPA office in Oakland, California. The specifications published were drafts. We're still working on them and hope to get the final specifications out next year.

There are twelve different plastic materials in the draft specifications, used in forty different combinations of thickness, formulation and reinforcement. However, the most commonly used ones are polyvinyl chloride (in 20 and 30 mil. thicknesses, unreinforced), chlorinated polyethylene (30 mil., unreinforced), and reinforced Hypalon (36 mil.). All the materials have good chemical resistance to all inorganic materials. As far as organic

solvents are concerned, we have to know what they are. Furthermore, for containment facilities for wastes said to contain COD or BOD, that designation alone is not enough. A better chemical definition is necessary.

We have to be able to say what the effects of the chemicals to be contained will have on the hydrocarbons, aromatic hydrocarbons, chlorinated hydrocarbons or alcohol present in the plastics. Any supplier in the business will want to know what is to be contained in the plastic material before he'll recommend a material, so we ask your cooperation. It will actually help the linings.

Basically, linings are used in two different ways in all the facilities we're talking about. They are buried membranes or exposed membranes. For buried membranes, the most frequently used membrane material is polyvinyl chloride. It has the lowest cost, has good properties, and has been used for a long time. I have a sample that I got recently that we put in twenty-five years ago, and it's unchanged. Polyvinyl chloride liners are made of a resin itself plus a plasticizer. That's a solvent, and, if the liner is exposed to sunshine, it will attain a high temperature and some of the plasticizer will be lost. Film temperatures of over 200°F have been measured, and theoretically they could get up to 300°F. However, if we cover the liner with earth, we keep the temperature down, and under those circumstances, PVC, as present-

ly compounded, can be employed for a long life. We need long-lasting materials that will be resistant to microbiological attack and low temperatures. We've been working on these for a long time, too. Twenty years ago we started writing specifications for ASGM.

Exposed membranes require a material that has no volatile plasticizer. For this application, we use chlorinated polyethylene, and, more commonly, Hypalon. The latter is preferred because of its reinforcement. For exposed membranes, we prefer a strong fabric with a high tear resistance. If it's going to be exposed to atmosphere, you have to anticipate you may get some holes from vandals. So we like to have a material that is resistant to damage, and can be repaired. Of course, it would be best to protect membranes, and earth coverings do that very well, but sometimes exposed membranes are necessary.

Plastic liners are chemically resistant because of their low, controlled permeability. Several years ago, Joseph Ward Associates tried to measure the permeability of PVC, and ran tests using a pressure of 60 psig. They were unable to measure any permeation, but calculated that the permeability was less than $10^{-12}$ cm. per sec. Tests on Hypalon produced similar results.

The U.S. Bureau of Reclamation states that good clay has a permeability of $10^{-6}$ cm. per sec., which is at least a million times as permeable as plastic.

On this basis, a thirty ml. plastic film would be equivalent to 2,500 feet of clay. On the other hand, the plastic liner doesn't have the liquid storage capacity of clay. That's one advantage clay has. You can accept a slow percolation in that thick layer. The EPA is requiring ten feet of clay equivalent to a twenty ml. plastic film.

Cost of linings of course will vary somewhat. A thirty ml. PVC liner should be installed for about 35¢ per square foot. When you get into larger areas, you could possibly get costs below that figure. Including the earth covering, installed cost would be about $25,000 per acre. Hypalon lining is more expensive, at about 65¢ per square foot, installed. However, it can be used on steep slopes.

Installation of linings is quite simple, but care must be taken. Although the strength of plastics per square inch is high, with the usual thickness utilized, the allowable stress is quite low, especially for unreinforced materials. Since the elongation is high, the sheeting will conform to surface irregularities, but these irregularities should be kept to a minimum as all materials perform better at low stress. Fabricators furnish linings in large pieces either folded in both directions, or folded in one direction and rolled in the other, so that they can be easily opened and joined to other sections in the field with solutions of resins. Figure 4 shows a folded and rolled sheet being "dispensed" directly onto the surface to be covered from the truck that brought it to the site.

Prefabricated sections can be factory assembled up to 12,000 lbs. weight. A 30 ml. piece weighing 4000 lbs, will be 25,000 square feet in area, more than half an acre. Figure 5 shows such a section being unfolded and spread by a team of eleven men. It took them one minute to lay the whole piece. To place the soil cover on top of a liner, bulldozers can be used, as shown in Figure 6. You could drive a bulldozer over a liner, if you had to, but there is always the fear of mechanical damage. So we always prefer to drive on top of the earth, and keep pushing it forward, as you can see in the figure. In order for the cover to be retained, side slopes should never exceed three to one.

In cold weather, hot air dryers have to be used when forming the field seams. Joints in the field are made with solutions of the appropriate resins, vinyl resin for PVC film, Hypalon resin for Hypalon film.

**Mr. Kane:** Julian Kane. My first question is: Assuming there is no organic solution that will deteriorate the lining, what is the estimated life span of linings in terms of maintaining integrity in a landfill? My second question is: Inasmuch as we do not know what goes into a landfill, legal or illegal, how can we be sure that the integrity will not be disrupted within a few years after its installation?

**Dr. Staff:** A plastic lining has a rather indefinite life. They ought to last more than fifty years. Regarding the second question: the earth cover initially will be wetted generally from rain, and so any waste on top of this soil will have to diffuse through the soil while being diluted, and so attack will be minimal. Another thing: Chlorinated hydrocarbon is heavier than water and might go through the soil. If you're covering with a fine mixture of soil, it will not go through the void spaces, because of surface tension between soil particles. If you have hydrocarbon which will float on water, then the soil covering is always wet from capillary action on the side slopes, and it acts as a barrier, so that the oil will not penetrate through the lining.

I remember one case where we had a liner where they dumped a lot of waste liquid material. We told them to cover the whole liner, but one area they didn't cover. There were no attacks on the lining where it was covered, but where it wasn't covered, a new section had to be installed.

**A Voice:** How reliable are the seams?

**Dr. Staff:** They should always be tight. Of course, the field seams do have to be checked, and we always suggest there be a properly qualified person in charge of the field work. Also, I've never found an opening in a factory seam, and I've checked a lot of them.

**A Voice:** Does the field seam have the same integrity?

**Dr. Staff:** It should have, and the joints are full strength.

**Mr. Watson:** Dick Watson, Brookhaven Town TAC. My question, following up on that last question, is: Were the seam tests appropriate for landfill sites? We have found that seams have only a couple of years lifetime.

**Dr. Staff:** Well, by some people in the past, adhesives were used to form seams, but we try to stay away from adhesives as they are generally not of the same composition as the base material and have different chemical resistance. Some of the adhesives will fail under shear stress quite easily.

Figure 4  *Folded and rolled sheet unloaded from truck*



Figure 5  *Section of liner being unfolded and spread*

Figure 6  *Bulldozer placing soil cover on top ot liner*



9

# Chemical Indicators of Leachate Contamination in Groundwater near Municipal Landfills

Dr. Robert A. Saar

Geraghty and Miller, Inc., Syosset, New York

## Abstract

*The monitoring method described here uses small wells located around the landfill in the saturated zone. Determining total dissolved solids and associated specific conductance is probably the easiest and most general chemical test to locate a leachate plume. Elevated chloride, bicarbonate, ammonia and potassium concentrations in relation to background groundwater levels are reliable indicators of leachate plumes. Another indicator is iron concentration. However, naturally-occurring high concentrations in local soils may obscure sampling results. Although sulfate may leach out of a landfill, substantial biological and chemical changes may occur, thereby often depressing the concentration of sulfate in a plume with respect to background groundwater levels. Elevated concentrations of boron, selenium and freon indicate specific origins of these chemical wastes including laundry detergents, printing processes and disposed refrigerators and/or air conditioners, respectively. Stiff Diagrams and Piper Diagrams are tools that aid investigators in reviewing data from extensive monitoring programs. Sampling monitoring programs should incorporate analytical redundancies as checking systems to identify unreliable data sets. These methods range from inexpensive statistical correlation analyses to sending replicate samples to several laboratires for analysis—an expensive endeavor.*

Our discussions today will be basically in three parts: a quick overview of the methods of monitoring, followed by a number of chemical clues that can be used to discern where a leachate plume is, and finally the problems involved in figuring out what data is reliable and what the data means. I'll make a few remarks on how you can ascertain a certain level of reliability when you're looking at the chemical data associated with a leachate plume.

## Monitoring Methods

Probably the most common method for monitoring is employed in the unsaturated zone. This is the area between the bottom of the landfill and the top of the water table, where there's partial filling of water in the soil pores, and the device used for this kind of monitoring is a pressure lysimeter. However, most of the business that our company engages in is monitoring in the saturated zone. That type of monitoring is done generally with small monitoring wells, but in a number of projects we've used larger wells, even fire wells already existing around the landfill, to monitor the contamination.

There are other methods. Generally, the leachate plumes will have more dissolved solids in them, and conduct electricity better. Therefore, with electrical methods, you can sometimes determine where a plume is, and how wide and how long it is. I'm not going to go into other methods, such as aerial photography, but there are a number of more exotic methods that can be used for monitoring the landfill.

## Chemical Indicators of Pollution

Most of my discussion will concern some of the chemical clues that can be used for monitoring a landfill.

Probably the most important chemical clue that you can use to start out with is to know what is in the landfill. I suppose you could look upon this as a detective mystery. The whole idea is to gather as much information from as many sources as possible; to know, perhaps, that it's a municipal landfill; trying to figure out if there's any industrial waste put in there intentionally or not; trying to figure out if unusual items are consumed or manufactured in a given area.

Once you know what's in a landfill, you can talk about general indicators of the leachate plume, and among these are the following:

Total dissolved solids is probably the easiest and most general chemical test that you can use to determine where a plume is, and related to that is specific conductance. Assuming that the greater part of your sample's solid content is charged and conducts electricity, you'll find in most cases that there is a strong correlation between the total dissolved solid content and the conductivity of the leachate water that you draw out of a lysimeter or a monitoring well.

**Chloride ion concentration:** I have found, in reviewing a great deal of data, that chloride ions increase in concentration most dramatically in a leachate plume, compared to the background water.

Another parameter that increases dramatically in leachate is **bicarbonate ion concentration.** Instead of

11

measuring bicarbonate, you can monitor alkalinity. Alkalinity is not strictly bicarbonate concentration, but there is a close correspondence between those two.

Probably the prime indicator of a leachate plume is **ammonia.** I've seen cases in the literature where ammonia concentrations are a thousand times higher in the leachate plume than in the background level of the groundwater adjacent to the landfill.

Another interesting parameter that is noted in the literature is **potassium.** It turns out that, at least in municipal landfills, there are a lot of foodstuffs which are rich in potassium. Probably the best test you can do is not necessarily look at the amount of potassium, but compare the ratios of **sodium** to potassium in the plume and the background. In background water, the ratio of sodium to potassium is about seven. As you move into the leachate plume, the ratio of sodium to potassium falls to about two. Sodium is still predominant, but the ratio is different between the clean water and the contaiminated water.

Another indicator is **iron.** Although I have found, from reviewing the literature, that iron can be a tricky indicator of where the plume is, I'd say about ninety percent of the time you'll find that iron is substantially elevated in the plume, compared to the background level. However, because so much iron exists in natural soils, local conditions unrelated to a leachate plume may cause high iron concentrations. Generally I would say that iron is a fairly good indicator, but care is necessary.

**Sulfate** is different from the indicators already discussed. Although sulfate may leach out of a landfill, substantial biological and chemical changes may occur. Consequently, perhaps three quarters of the time, or more often, you'll have a lower concentration of sulfate in the plume than you have in the background. Also, the strongly reducing conditions in leachate provide a good environment for converting sulfate to sulfide.

Let me give you some specialized chemical indicators of leachate plumes. A specialized indicator might be something like **boron.** If you spray laundry water that has Borax in it on a landfill, boron will appear in the leachate. Another specialized one might be **selenium.** Some processes, printing, for example, generate wastes containing selenium. If you find elevated amounts of selenium in groundwater samples, it is evidence of a leachate plume, since background levels of selenium, in most parts of this country, are low.

**Freon** could be another specialized indicator. It's used as a working fluid in refrigerators and air conditioners, so you may find a lot of freon in a landfill where air conditioners or refrigerators have been disposed of and the freon has not been removed beforehand.

I've given you a list of eight to ten different indicator chemicals. When reviewing the data collected in an extensive monitoring program, you can encounter conflicting trends and become confused. You need some kind of device that displays more general patterns of data. Among the techniques that have been developed are different kinds of diagrams. One of them is called the **Stiff Diagram.** Figure 7 is an example.

What we have here is data taken from one of the earlier Babylon studies by Kimmel and Braids, done during the 1970's. At the top of the figure is a linear scale denoting concentration. The scale is centered on zero,

MILLIEQUIVALENTS PER LITER
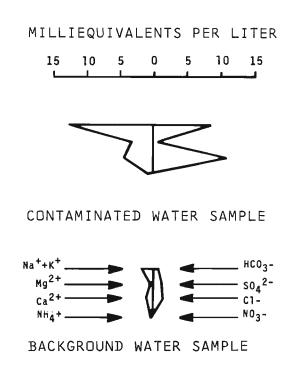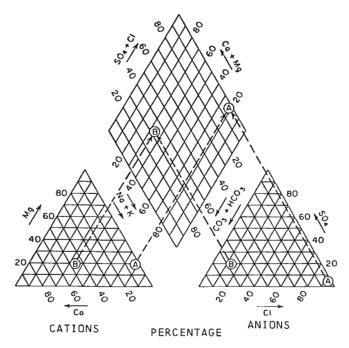
Figure 7 *Stiff Diagram on a ground water sample taken near Babylon Landfill*

with concentrations of positive ions extending to the left and negative ions to the right. At the bottom of the figure is a diagram representing the composition of an uncontaminated background sample. The narrowness of the diagram indicates the low concentrations of the listed ions. In the middle of the figure, there is a diagram representing a contaminated sample. Its greater width shows how much higher are its ion concentrations than those of the background sample. Except, that is, for sulfate. The deep indentation on the right (negative ion) side of the diagram illustrates the comment, made earlier, that the sulfate content of leachate will usually be lower than background.

Another kind of display is the **Piper diagram,** Figure 8. In the illustration shown, samples of sea water and potable groundwater are compared. This type of display has the advantage of emphasizing differences between samples by separating them widely in the diagram. The Piper diagram uses two trilinear diagrams for plotting cations (bottom left) and anions (bottom right) and combines them in a quadrilinear diagrom (top). By joining the points in the three diagrams that pertain to a particular sample, disparate samples can be compared without confusion.

### Reliability of Data

Let me give you a few pointers about reliability. I think it's a matter of great concern. I know that when I have to write a report about a landfill, I often find myself having to draw conclusions from data that's sometimes conflicting. What you have to do is build into your sampling/monitoring protocol certain kinds of redundancies, which will help you figure out which of the data is unreliable. There are several ways of doing this, some expensive, some cheap. The cheap methods include the following: I

Figure 8 *Piper Diagram*

have already alluded to total dissolved solids and specific conductivity readings. The specific conductivity reading is done in the field. Total dissolved solids is done in the laboratory. There should be a fairly good correspondence between the two. It's often possible to eliminate a bad data point by looking for that correspondence.

Another relatively inexpensive test you can do is analyses for hardness, in addition to your measurements of magnesium and calcium. If you see a radical difference between the hardness value and the sum of your magnesium and calcium values, you can be sure the data is bad.

Another additional measurement you can make in the field is pH. You can compare that to the measured concentrations of carbonate and bicarbonate, and you'll find, for example, that very little carbonate can exist unless your pH is high. Thus, if you have a high carbonate value and your pH is seven, you know something is wrong.

Another possibility is to take the oxidation reduction or redox potential. That's a measure of the supply of electrons in your system. You can compare that, for example, to sulfate and sulfide values. With a low redox potential, you would not expect a high sulfate figure. A high redox potential would be expected to accompany a high sulfate reading.

These are relatively inexpensive redundancies I've suggested here. There are a couple of more expensive tests you can do to increase your reliability. One is to analyze replicate samples. However, doing replicates and triplicates on a lot of your samples is an expensive procedure.

What you can also do is to send in spiked samples. Anybody here who has been involved in laboratory work,

using analytical instruments, knows that certain kinds of samples will interfere with an instrument's performance, and distort the results. Adding known amounts of a constituent to extra aliquots of sample and submitting them to the lab can help to determine whether these effects are serious. If they are, and a revised laboratory procedure cannot be developed, the importance of the affected data should probably be reduced.

Another expensive method is to use several different laboratories. You can send replicates to the same laboratory or take representative replicates and send them to different laboratories. Of course, most of the time you don't have enough money to send many samples to many laboratories. This interlaboratory testing with spiked samples and replicates is what the EPA has tried to do, but those programs have been strictly federally funded.

**Mr. Wolterding:** Dennis Wolterding, NYSDEC. I notice you included iron on your short list of indicators. Have you used **manganese** values as well? High manganese in background are very, very unusual. Also, when you get a very high ratio of iron to manganese, you're sure you're dealing with a steel source. We have found it to be an excellent indicator to go along with iron. I wonder if you have the same experience.

**Dr. Saar:** I would say you're correct in saying that manganese is as useful an indicator as iron. However, I've seen more variability in the manganese data that I've looked at. I've seen occasions where the background is higher than the contaminated area. Moreover, manganese concentrations, even when elevated, are typically much lower than iron concentrations. Hence, for manganese, you may be adding to uncertainties as the analyst is pushed close to the detection limits of the instrumentation.

**Mr. Bruser:** George Bruser, Brookhaven. In trying to predict where leachate plumes are going to end up, and considering the type of soil on Long Island in different locations, do you think it's fair to say that the soil is basically homogeneous, so that you could predict certain interactions, and know how high a concentration of an ion in the groundwater you would need in order to be able to say that a particular area is affected by a leachate plume.

**Dr. Saar:** A number of studies I have seen, including the Babylon study that I referred to and several others, give an indication about the kind of predictions you can make. I wouldn't want to put a number, saying, for example, you have to find twice as much conductivity as the background before you know a plume is there. I have to do it on a case-by-case basis, looking at a number of different chemicals at one time. I guess I'm big on pattern recognition. It's not easy to talk generally about soils. There's a tremendous amount of heterogeneity, even in small areas. Furthermore, what chemicals are you going to use to tell where the plume is? Chloride moves fast. Many other chemicals move more slowly. When examining a particular area, an important question to ask is: **What's your intended use for the water, or the land under which that water lies?** That also may affect your judgement of the situation.

Mr. Bruser: You're saying a site specific analysis is needed?

Dr. Saar: Yes. For example, you may be misled unless you know the geology very well. You might have thick layers of sand or clay in one place, and shallow solid rock in another. Even in areas of solid rock, the number of fissures, and their interconnections, determine how fast water and contaminants migrate. Most plumes are mapped as regular geometric figures. This regularity, however, does not arise from the simplicity of the groundwater flow pattern or the homogeneity of the aquifer. It arises from an incomplete data set.

Mr. Cunningham: Bill Cunningham. What did you use to make sure that you got a representative sample at twenty-five to thirty feet depth?

Dr. Saar: When we have sampled at that kind of depth, we have used bailers and pneumatic submersible pumps. Depending on the size of your well, you can lower that kind of pump down the casing to the saturated zone. Compressed air opens and closes a bladder, which drives the water sample up to the surface. There's no contact between the air that you use to power the pump and the sample itself, so you don't have to worry about losing dissolved volatile organics.

Mr. D'Antonio: Bill D'Antonio, Town of North Hempstead. I am concerned about the effect of organic compounds on the integrity of vinyl liners. Could you comment on the concentrations of organic compounds you have seen?

Dr. Saar: Concentrations I've seen lie in the range of several parts per million or milligrams per liter. I'm not an expert on liner reliability under those conditions. Perhaps somebody will address that in a later talk.

# Collection and Treatment of Leachate from Sanitary Landfills

John DeFilippi
ERM-Northeast, Syosset, New York

## Abstract

*The quality of leachate from sanitary landfills varies spatially among sites and temporally within a given site. The highly contaminated nature of this waste water presents difficulties for treatment. Hydrology and age of the site, climate and season, the content and height of the refuse pile and moisture routes through the pile influence the quality and quantity of leachate emanating from a landfill. The collection of leachate from more recent landfills is facilitated by underlying liners and collection pipes; leachate collection from older landfills that lack liners relies on interception trenches and/or recovery wells. It is a common practice to collect leachate and recycle it through the fill. This initially precludes the need for a treatment facility and allows the leachate and landfill to reach an equilibrium in which the quantity and quality of the leachate become consistent. Leachate can then undergo biological treatment, chemical/physical treatment or a combination biological/chemical/physical treatment. however, if the leachate contains toxics such as heavy metals, a preliminary treatment must precede any biological treatment. The type and degree of treatment depend on the character of the leachate and the site where the treated material will be disposed. The prime consideration should always be the reduction of the quantity of liquid to be handled.*

## Quality of Leachate

The first point I want to make is that, before leachate collection and treatment can be undertaken, there are two major considerations that have to be kept in mind. First of all, the quality of leachate is extremely variable. It varies from site to site, and it varies at the same site over time. So predicting exactly what the constituents are going to be could be quite difficult. The second thing that has to be remembered is that leachate is very highly contaminated waste water. It has all kinds of nasty constituents in it, and it's very difficult to treat.

First of all, with respect to variability of quality, I've tried to list in Table 1 some of the factors that determine the quality of leachate emanating from a particular landfill. Obviously, refuse characteristics play a large role, as do hydrology of the site, climate, the season of the year (which affects current rainfall), the age of the site, the height of the refuse pile and how long a leachate path the liquid had to follow prior to reaching the bottom of the fill. Also very important are how the fill has been placed, what cover material has been used and what the moisture routing through the refuse pile looks like. When you put together the seven factors, you can see that every fill is designed and operated differently, and you can expect a wide range of characteristics in the leachate liquid that you're trying to treat.

## TABLE 1
### Factors That Determine Quality of Leachate

- REFUSE CHARACTERISTICS
- HYDROGEOLOGY OF THE SITE
- CLIMATE
- SEASON
- AGE OF THE SITE
- HEIGHT OF REFUSE
- MOISTURE ROUTING THROUGH REFUSE

Just to give you some idea of the kind of variability, take a look at Table 2. This is a composite of data that has been collected from a number of landfills, handling essentially clean municipal refuse, but you can see there's a great deal of variabiility. Look at some of the loadings in the average column. COD and BOD, at thousands of parts per million; high nitrogen and calcium. Some of the metals are high as well. Not only are the loadings high, but, if you look at the Minimum and Maximum columns, you will see a wide range in the values you can expect coming out of the bottom of the landfill.

However, those characteristics are going to change as the material undergoes decomposition. See Table 3. Constituent concentrations that are high early in the life of a fill generally decrease with time. Again, Table

# TABLE 2
## Leachacte Characteristics
### (The leachate characteristics included in this table are a composite)

| Constitutent | Minimum | Concentration (mg/l) Average | Maximum |
|---|---|---|---|
| pH | 4.0-6.0 | 5.5-6.5 | 6.5-8.5 |
| Iron | 6.0 | 100-800 | 1,600 |
| Phosphate | 0.3 | 7-13 | 30-130 |
| Sulfate | 30.0 | 300-400 | 500-700 |
| Chlorides | 100.0 | 300-400 | 2,400 |
| Sodium | 85.0 | 300-1,000 | 1,000-4,000 |
| Nitrogen | 20.0 | 150 | 500 |
| Org. Nitrogen | 2.0 | 225 | 500 |
| Ammonia Nitrogen | 0.2 | 300 | 550 |
| Hardness ($CaCO_3$) | 200.0 | 2,000 | 5,000-7,000 |
| Alkalinity ($CaCO_3$) | 700.0 | 8,000 | 9,500 |
| COD ($O_2$) | 100.0 | 21,000 | 50,000 |
| BOD ($O_2$)* | 100.0 | 16,000 | 30,000 |
| Suspended Solids | 100.0 | 500 | 2,000 |
| Total Solids | 1,000.0 | 20,000 | 40,000 |
| Calcium | 100.0 | 1,500 | 2,500 |
| Magnesium | 60.0 | 250 | 420 |
| Potassium | 30.0 | 1,200 | 1,800 |
| Zinc | 0 | 15-30 | 135 |

*20 day

# TABLE 3
## Effects of Age on Leachates from Sanitary Landfills

| Constitutent | 6 Months | Concentration (mg/l) 6 Years | 12 Years |
|---|---|---|---|
| Arsenic | 4.31 | 0.1 | 4.6 |
| Chloride | 1,697 | 1,330 | 135 |
| Copper | 0.05 | 0.05 | 0.05 |
| Cyanide | 0.024 | 0.005 | 0.02 |
| Fluoride | NR | 2 | 0.31 |
| Total Iron | 5,500 | 6.3 | 0.60 |
| Manganese | 1.66 | 0.06 | 0.06 |
| Nitrate | 1.70 | 0.70 | 1.60 |
| Sulfate | 680 | 2 | 2 |
| Total Dissolved Solids | 19,144 | 6,794 | 1,198 |
| Zinc | NR | 0.13 | 0.10 |
| Barium | 8.5 | 0.80 | 0.30 |
| Alkalinity ($CaCO_3$) | 3,255 | 4,159 | 1,011 |
| Total Hardness ($CaCO_3$) | 7,830 | 2,200 | 540 |
| Phosphate | 6 | 1.20 | 8.90 |
| Sodium | 900 | 810 | 74 |
| BOD** ($O_2$) | 54,610 | 14,080 | 225 |
| COD ($O_2$) | 39,680 | 8,000 | 40 |
| pH | NR | 6.3 | 7.0 |

*Leachates collected at base of fill material

**20 day          NR   Not Recorded

3 gives composite values and representative averages that can be found in the literature. You'll see that when leachate first begins to show up in the underflow, concentrations are very, very high. As decomposition and leaching proceed, and assuming that you're not putting the leachate back on the fill, the quality of the leachate will change with time. It generally tends to become cleaner over the years, but it's still a nasty material to have to handle and deal with.

## Leachate Collection

With regard to collecting leachate prior to treatment, there are basically two situations we encounter. (See Table 4). Newer landfills are lined, of course, and their collection is fairly straightforward, with perforated pipe collection systems similar to the one that was described by the first speaker. Figure 9 shows a typical detail of the collection point of such a system. Perforated pipe is laid with granular material packed around it. Pipes can be laid in a radial pattern, so that leachate flows from a number of areas within a landfill, to a central collecting trough or, as shown, collecting manhole. From this point, the leachate can be pumped or routed to a sump.

Older landfills, those without liners, present a much more difficult collection problem. As Table 4 indicates, the main methods in this case are interception trenches and recovery wells. Figure 10 illustrates the interception trench concept. In the particular case shown, the landfill happens to be sitting close to the water table. All the groundwater is flowing to the right. If the plume can be identified, related collection and intercepting trenches can be built, and leachate collected.

## TABLE 4
## Collection of Leachate
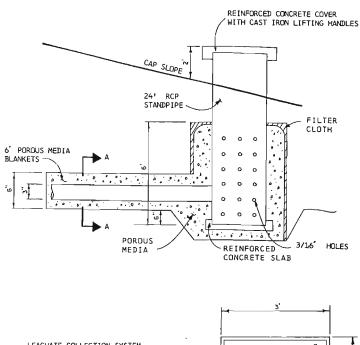
**LINED LANDFILLS**
- SLOPE BOTTOM OF LANDFILL
     TO INTERCEPTION TRENCHES OR SUMPS
- PERFORATED PIPE SYSTEMS TO SUMPS

**UNLINED LANDFILLS**
- INTERCEPTION TRENCHES
  - BELOW GRADE
  - AT SURFACE INTERSECT
- RECOVERY WELLS
  - THROUGH THE FILL
  - DOWN GRADIENT

Obviously, you'll be collecting a lot of clean groundwater. This is one method of collecting the leachate, if you're dealing with this kind of hydrological region.

Some areas of Long Island have perched groundwater. Plumes do exist in such locations and, if so, the flow of groundwater can sometimes be collected at a surface intercept, as shown in Figure 11. Generally, this is not the case, and Figure 10 shows the situation that generally prevails in Nassau and Suffolk.
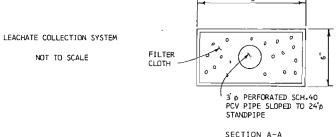


Figure 9   *Leachate Collection system*

Perhaps the method must frequently used to try and remedy conditions created by building landfills that are not lined employs recovery wells. Figure 12 displays two simple schematics that indicate the kind of recovery well systems that one might use. There's a free water table somewhere below the landfill. In the first case, the recovery well is actually constructed through the landfill, and pumped liquid is then taken to a treatment facility. The second condition is much like the one shown in Figure 10, where an interception trench was used. However, you might use this approach if the ground water table is fairly deep and the construction of an interception trench is too expensive. Here the recovery well is located down gradient. The plume begins under the landfill and the groundwater flow is to the right. The plume is pumped and the leachate is taken to a facility for treatment.

## Leachate Treatment

Once you have the stuff, your next problem is to decide how to treat it or what to do with it. Let us study Table 5, and before I talk about the treatment alternatives, consider the **Primary Objective**, which should be to minimize the amount of leachate being generated. It's nasty stuff to handle and treat, and you want to do as much flow reduction as you can, because it will automatically pay for itself in the long run.

## TABLE 5
## Treatment of Leachate

**PRIMARY OBJECTIVE: MINIMIZE THE AMOUNT OF LEACHATE BEING GENERATED**

TREATMENT ALTERNATIVES
- RECIRCULATION ONTO THE LANDFILL
- BIOLOGICAL TREATMENT
  - AERATED LAGOON
  - ACTIVATED SLUDGE
- PHYSICAL/CHEMICAL TREATMENT
- COMBINATION OF BIOLOGICAL WITH PHYSICAL/CHEMICAL
- DIVERSION AND TREATMENT AT A MUNICiPAL SEWAGE TREATMENT PLANT
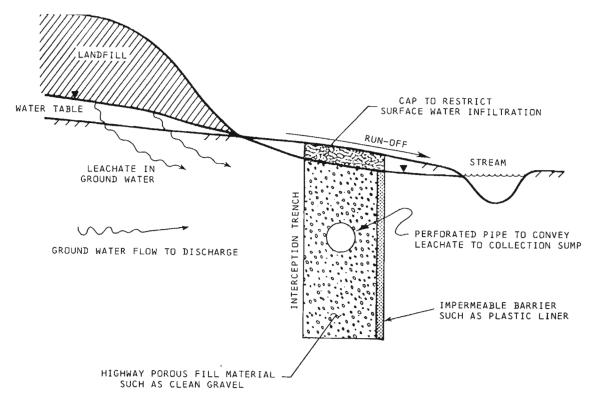
Figure 10  *Leachate interception trench concept*
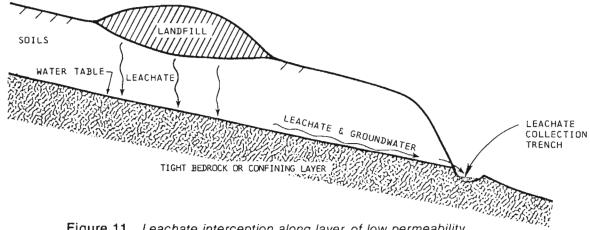
Figure 11  *Leachate interception along layer of low permeability*
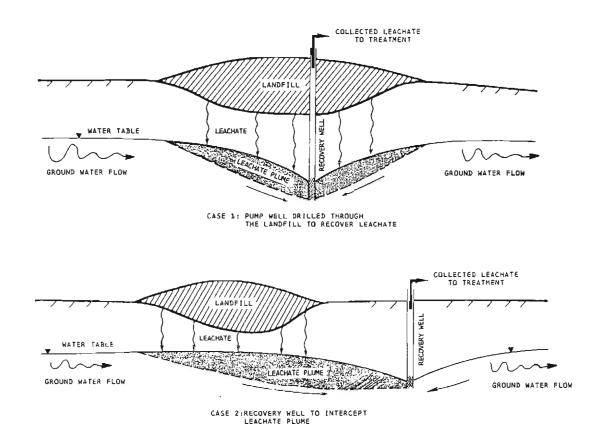
Figure 12  *Recovery well concepts for leachate collection*

There are several speakers after me who are going to talk about capping, so I'm not going to spend any time on that, but obviously capping and routing surface water around the landfill, all the methods that you can use to minimize the amount of leachate generated should be taken initially so that you only have to deal with a small quantity.

During the early years of a landfill, it has been a common practice to collect the leachate that's coming out at the bottom, pumping it back on the fill, and letting it recycle through the fill. This accomplishes several things. First of all, it precludes having to build a treatment facility initially. Secondly, it gives the landfill and the leachate time to reach equilibrium. If you can recycle back on the fill for a period of a year or two, you'll eventually reach a point of equilibrium, where the quantity of leachate as well as the quality characteristics become fairly consistent, and that's a large part of the battle.

If you have a leachate with constituents that you know, you're in a better position to treat it, so recirculation onto the fill is a possibility. Biological treatment is a possibility. Physical-chemical treatment is a possible combination, biological and physical and chemical is possible, and treatment at a municipal sewage treatment plant is another possibility if there's one in the area.

Biological treatment has historically taken two forms: the aerated lagoon approach and the various other forms of activated sludge treatment. Figure 13 shows very simplified flow diagrams of both approaches. The aerated lagoon is a relatively ineffective treatment mechanism. It doesn't allow you to control the process, and the level of treatment that you get is fairly low. However, if you are coming to a municipal treatment plant for treatment, that might be an appropriate pre-treatment step.

Some of the more sophisticated activated sludge treatment approaches are possible. In all cases, we recommend that some form of equalization tank be placed in front of the activated sludge process, primarily to take shock loads and prevent shock loads getting to the biological processes. Some form of preliminary treatment may be necessary, e.g. perhaps heavy metals have to be removed. A number of biological treatment processes have been tried. Figure 13 shows several: activated sludge, rotating biological contactors, marsh-pond systems, oxidation ditches and others. The important point here is that some form of equalization has to be provided up front, and you have to make certain that you're providing the necessary preliminary treatment. It's virtually impossible, as far as we're concerned, to design any of the systems out of a textbook.

After a leachate has reached a condition of equilibrium, we strongly recommend that treatability studies be conducted on the waste water. It may be that leachate from that particular landfill cannot be treated. If a landfill has sludge, if a landfill has pumpage from a septic tank, if there's been industrial waste deposited in the landfill in the past, treatment may not be possible at

19

all, so treatability is very important.

Finally, physical-chemical treatment is becoming popular (See Figure 14.). Again, we attach a great deal of importance to equalization up front, to equalize the quality of the leachate coming to the physical-chemical plant. Sometimes solid loadings can be heavy. To prevent undue fouling, some form of solid separation is necessary, and filters have been used. Carbon adsorption can be used, and it's not a bad idea to provide effluent storage.

Of course, the type and degree of treatment that you provide will depend upon the character of the leachate that you're handling, as well as where the treated effluent is to be disposed of. If effluent is to be discharged to ground, treatment becomes a very difficult problem. On the other hand, a discharge to surface water need not be quite as clean.

Finally, I mentioned the combination of biological and chemical (See Figure 15.). This system has been recommended for study for landfills in Suffolk County. It really is a combination of the two that we spoke about earlier. Again, equalization is very important. If discharge is to be to the ground, and the leachate has high concentrations of heavy metals, then some form of metal removal must be included. Perhaps pH adjustment prior to the biological treatment process will be necessary. Biological treatment options are available. Figure 15 shows the possibility of polishing effluent with a marsh-pond system, dual filters or nitrogen removal. Finally, I want to emphasize again that the absolute prime consideration should be to reduce the quantity of this liquid that you have to handle.
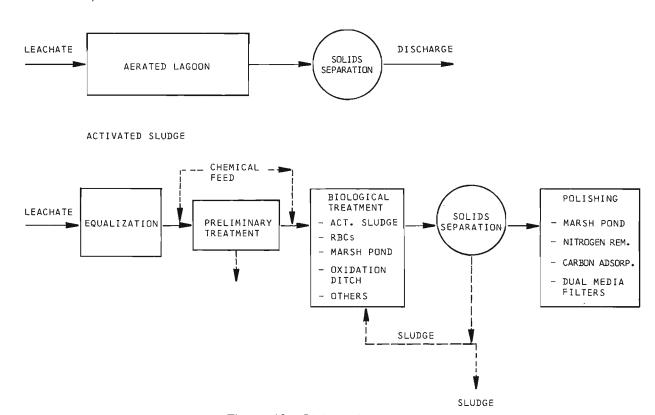


Figure 13  *Biological treatment*
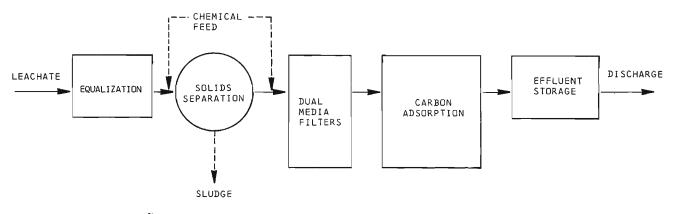


Figure 14  *Physical/Chemical treatment*

20

PHOSPHORUS ADDITION

**LIME

**FERRIC CHLORIDE

**UTILIZE ON-SITE TREATABILITY STUDIES TO DETERMINE
DOSAGE & DESIGN PARAMETERS

LEACHATE

EQUALIZATION → METALS REMOVAL

SLUDGE VACUUM FILTRATION

BIOLOGICAL TREATMENT**
ROTATING BIOLOGICAL CONTRACTORS
ANAEROBIC FILTERS
OXIDATION DITCH
OTHERS

EFFLUENT POLISHING**
MARSH-POND
NITROGEN REMOVAL
DUAL MEDIA FILTERS

DISCHARGE

*LEACHATE

EQUALIZATION/ PRO-TREATMENT

SOLIDS TO LANDFILL

COMPOSTING → COMPOST APPLIED TO LANDFILL FOR ADDITIONAL COVER

Figure 15   *On-site physical/chemical/biological treatment*

**Mr. Salomon:** Figure 14 indicates dual media filters. What media did you have in mind?

**Mr. DeFilippi:** Sand, gravel, anthracite.

**Mr. D'Antonio:** Bill D'Antonio from Multi-Town. You recommended the recycling or recirculation of leachate in order to establish a leachate which would be stabilized. It seems to me there should be quite a difference in the leachate composition between the time when the landfill is unsaturated and the time when it is saturated.

**Mr. DeFilippi:** There is.

**Mr. D'Antonio:** I don't think there's anything in the literature at this point that could describe to us what kind of leachate we can expect from an unsaturated condition, but as the Town of Smithtown's landfill continues to develop, and we obtain this data, it may very well be that no pre-treatment is necessary in an area like Long Island, where we get forty, forty-five inches a year of rain annually. It shouldn't mean treatment in most landfills of more than six to ten thousand gallons a day.

**Mr. DeFilippi:** Are you suggesting that before the fill is saturated, the leachate might not be recycled?

**Mr. D'Antonio:** That's right, it could be removed, and either trucked or piped into a public treatment system.

**Mr. DeFilippi:** Possibly. It involves cost, but it's possible, yes. The point I was trying to make was that there's no question that the quality of the leachate is going to change over time. So, if you get a sample over six months and you think that's the animal you have to deal with,

and you want treatability studies two years from then, you might have some problems.

**Mr. D'Antonio:** I don't think that what you're doing, though, by recycling, would actually indicate to you what the change would be over time. There may not be any change over time in the landfill if it's never allowed to develop into a saturated condition.

**Mr. DeFilippi:** You mean the water is percolated through in a rapid fashion? I tend to doubt that's the condition, but it could be. However, biological decomposition is going on over time as the leaching continues over time. I'm sure the quality perameters will change, but by how much we don't know.

**Mr. Albanese:** Al Albanese, Long Island Sanitation. Has it been determined that leachate, all leachate, must be treated or handled in some way?

**Mr. DeFilippi:** I'm going to ask somebody from one of the regulatory agencies here to answer that question. I can't conceive of a situation in the bi-county area where a regulatory agency would allow any disposal of leachate without treatment.

**Mr. Wolterding:** That's an important question, and Mr. DeFilippi is right. No direct discharge of leachate to groundwater (or surface waters) is allowed under Part 360, unless it can be shown that the leachate meets the appropriate regulatory standards for discharges to those waters without treatment. In that case, of course, it wouldn't be a leachate at all. The regulations governing discharges to groundwater are set forth in 6 NYCRR Part 703.

# Capping Designs for Landfill Closure

JAMES J. WALSH, P.E.
SCS Engineers, Covington, Kentucky

## ABSTRACT

*The objectives of landfill capping include health, aesthetic and site use considerations. Cover materials are subdivided into four categories: 1) native soils, 2) soil blendings, 3) soil additives and cements, and 4) nonsoil covers or membrane liners. Native soils include gravel, sand, silt, and clay, each of which has a specific application. For example, clay is most suitable as a barrier to infiltration; gravel minimizes erosion and permits gas escape. Soil permeability can be adjusted by blending soils of various grain sizes. The addition of cement, lime and/or fly ash increases the strength of soil covers. However, these covers have an increased susceptibility to cracking as a result of differential settlement of the landfill and freeze-thaw cycles. Non-soil covers include: 1) portland cement materials, 2) asphaltic materials, 3) soil sealants and liquid spray rubber, 4) synthetic polymeric membranes, and 5) waste materials. These materials have different efficacies and costs, and should be considered on a site-specific basis. A landfill in Windham, Connecticut was successfully covered with 4 inches of sand, a PVC liner and 18 inches of fine sand and gravel; the top layer was vegetated subsequently. At present, an assessment of the effectiveness of the cover is incomplete. However, the plume has regressed perceptibly.*

I'll be speaking today on capping design for landfill closure. Mine is actually the first of three presentations that will deal with landfill closure. The other two are addressed to planting and runoff control.

I am somewhat of a foreigner to New York State. We have done a lot of work in New York State, but I have attained a federal perspective over the years, and I thought I would give a little background of solid waste regulations as they are nation wide and from which Part 360 of New York State regulations evolved.

The Resource Conservation and Recovery Act (RCRA) was enacted in 1976. That was the law and still is the law which addresses solid waste in the nation. It addresses the solid waste generated currently and in the future, and solid wastes that have been generated in the past. Subtitle D addresses municipal solid waste, management planning of solid waste, grants to the states and municipalities, resource conservation, and also the land disposal of waste. Under Subtitle D, each one of the states is required to conduct an open dump inventory, as it were, of solid waste disposal in the state, and that includes landfills, land spreading facilities and wastewater lagoons.

Under Section 4004 of RCRA, the EPA was required to establish criteria for the classification of solid waste disposal facilities (See Table 6.). They were pro-

mulgated in 1979 in the Federal Register, and upon those criteria the state agencies are operating, and certainly the open dump inventory is proceeding based on those criteria. Essentially, any identified landfill has to be evaluated as to its environmental stability and its compliance with the criteria. Those found in compliance are deemed sanitary landfills. That's a legal, not a technical term, and they're allowed to continue in operation. Those found in violation of the criteria are deemed open dumps. Again, this is a legal, not a technical term, and such facilities are required to close or to upgrade in accordance with a state-mandated schedule, not to exceed five years.

*Criterion 1:* There is a strong presumption that landfills are not located in flood plains.

*Criterion 2:* The matter of endangered species definitely has to be addressed for a new or existing landfill.

*Criterion 3:* In the matter of surface waters, point source discharges of leachate are of great concern. Any facility that has a point source discharge is required to have a permit. Others require quality management planning for the area. Lastly, no disposal of dredge spoil is to be permitted in a sanitary landfill.

## TABLE 6
## RCRA 4004 Criteria

1. Floodplains
   - base flood flow
   - temporary water storage
   - washout of solid waste

2. Endangered Species
   - endangered species
   - critical habitats

3. Surface Water
   - point source discharge
   - non-point source discharge
   - discharge of dredged material

4. Groundwater
   - contamination beyond solid waste boundary

5. Land Application on Food Chain Cropland
   - cadmium
   - PCB's

6. Disease
   - disease vectors
   - sewage sludge and septic tank pumpings

7. Air
   - open burning
   - state implementation plan

8. Safety
   - explosive gases
   - fires
   - bird hazards to aircraft

*Criterion 4:* Groundwater contamination is *not allowed beyond the solid waste boundary.* That condition is most difficult to determine and is going to get the greatest amount of attention in the course of the investigation of a landfill.

Criteria for contaminants have been set up, and those levels are not to be exceeded at the solid waste boundary, as differentiated from the property boundary. If they are exceeded in the natural groundwater, then no increase is to be seen in comparing up gradient and down gradient levels.

*Criterion 5:* Land application on food chain crops. Clearly, any toxic materials, such as cadmium and PCB's, cannot be allowed to enter the food chain.

*Criterion 6:* Disease vectors and sewage sludge and septic tank pumpage. This criterion pertains to the application of a cover to keep down odor, rodents, flies and other problems.

*Criterion 7:* Open burning is obviously prohibited, and attention must be given to compliance with state implementation.

*Criterion 8:* There are criteria in addressing fires and other hazards. What are the remedial or upgrading measures deemed applicable to bringing open dumps into compliance with the criteria? Refer to Table 7.

## TABLE 7
## Remedial Measures for Upgrading Landfills

Surface Water Controls
   1. Surface Sealing
   2. Revegetation
   3. Contour Grading
   4. Surface Water Diversion Structures
   5. Sedimentation Basins and Ponds
   6. Dikes

Groundwater Controls
   7. Well Point Extraction Systems
   8. Deep Well Extraction Systems
   9. Drain Extraction Systems
   10. Injection Systems
   11. Bentonite Slurry Trench
   12. Grout Curtain
   13. Sheet Piling Cutoff
   14. Grout Bottom Sealing

Gas Migration Control
   15. Vent Trench
   16. Barrier Trench
   17. Gas Extraction Wells

Waste Control
   18. Treatment of Contaminated Water
   19. Chemical Fixation
   20. Chemical Injection
   21. Excavation and Reburial
   22. Leachate Recirculation

We have *surface water controls, groundwater controls, waste controls and gas controls.* The first two of those, surface water controls and groundwater controls, are involved in surface sealing, capping, covering. That's the main thrust of my presentation. Such measures include revegetation, surface water basins, et cetera. There are straightforward considerations, relatively cost effective, certainly less costly than the technical groundwater controls. For groundwater control, there are both active and passive controls. Some of those were addressed in the previous presentation. Under active controls, we have well point and deep well extraction systems and drain injection systems. Passive systems require no ongoing action, and they include bentonite slurry trenches, grout curtains and sheet piling cutoffs.

Gas migration controls include passive and active systems, including barrier trenches and gas extraction wells. Listed under waste control is the injection of chemicals in the waste. This really hasn't been tested that much on a full landfill or full disposal facility.

Leachate recirculation is practiced in many applications. It isn't necessarily a final solution of the problem.

What are the objectives or requirements of landfill capping? The EPA has identified four different categories as listed in Table 8. There are *health considerations, aesthetic considerations, site use and other considerations.*

## TABLE 8
## Objectives of Landfill Capping

### Health Considerations
1. Minimize water infiltration
2. Control erosion and sedimentation
3. Promote free venting of gas
4. Prevent and/or contain fires
5. Control flies, rodents, and birds

### Aesthetic Considerations
6. Control blowing paper
7. Control noxious odors
8. Provide sightly appearance

### Site Use Considerations
9. Provide vehicle support
10. Ensure workability of equipment
11. Promote vegetative growth
12. Provide for site end use

### Other Considerations
13. Control wind erosion and dust generation
14. Resist cold climate impacts
15. Maintain slope stability
16. Resist cracking

Under health considerations, we have the most important ones, including minimize water infiltration, control erosion and sedimentation, and control disease vectors, flies, rodents and birds.

With regard to aesthetic considerations, you want to control blowing paper and noxious odors, and provide a sightly appearance. That question seems like a health concern as well.

Site use considerations include the need to enable vehicles and equipment to operate satisfactorily. The promotion of vegetative growth goes hand in hand with provision for site end use. Other considerations include controlling wind erosions and dust generation, and resisting low temperatures. You also need to maintain the slope and resist cracking in dry weather conditions.

Figure 16 illustrates the hydrologic cycle at landfills.

I'm sure you've seen this before. You have moisture in the landfill. How is it getting there?

- *It can be in the waste as it's delivered.*
- *There is the water table below the refuse.*
- *The predominant source of water, is precipitation and irrigation, if the landfill is irrigated.*

Not all precipitation enters the refuse pile. Some is lost to the atmosphere through the mechanism known as evapotranspiration. Some flows away by surface runoff.

Another source of moisture on the top of the landfill is upland drainage. To prevent that, you can use cut-off ditches, a relatively cost-effective device.

### Types of Cover Material
For purposes of this presentation, available soil materials are subdivided into four areas as follows:
- *Native soils*
- *Soil Blendings*
- *Soil Additives and Cements*
- *Non-Soil Covers or Membrane Liners*
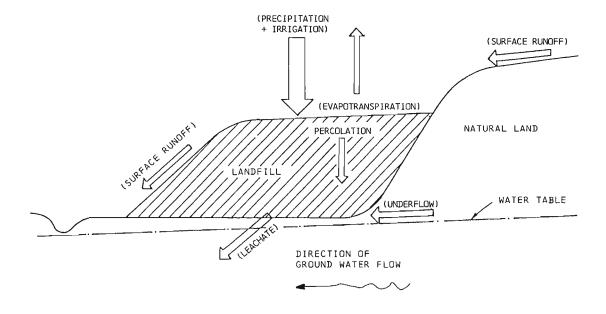


Figure 16  *Hydrologic cycle at landfills*

25

The following sections will address design and construction details, as well as the applicability of each of these cover materials.

*NATIVE SOILS*

The suitability of native soil types for cover materials has been delineated in Table 9. Available soil covers have been grossly classed into four general types of illustration purposes:

- *gravel*
- *sand*
- *silt*
- *clay*

Suitability of each of these respective soil types has been delineated against various health, aesthetic, site end-use, and other considerations.

The first item under *health considerations* in Table 9 is infiltration. Obviously, clay appears to be the most suitable cover. You can see that gravel and sand are generally unacceptable. For erosion and gas problems, on the other hand, you're going to have fewer gas prob-

lems if you have a gravel or very porous type of cover material, whereas, clay may cause problems in promoting gas migration. As far as fires are concerned, you want something that is going to keep oxygen out of the refuse mass, and the application of clay cover or other finer soils prevents fires. Clay and silt keep down flies, while gravel and sandy soils are more suitable for control of rodents. For bird control, virtually any soil will do.

*Aesthetic considerations:* Virtually any soil would be acceptable, except that gravel, being highly porous, would be of no help against noxious odors.

*Site use considerations:* Sand is going to drain readily and would be your best choice for vehicle support. For workability, gravel, perhaps, is going to be the most suitable, and clays the least suitable. For vegetation, no soil type is going to work really well alone, and the choice will depend on the end use.

*Other considerations:* Obviously, the coarser the cover material, the less it is subject to wind erosion and dust. As far as cold weather is concerned, generally, the better the cover drains, the fewer the problems you're going to have, particularly if it was originally wet from a frozen season.

# TABLE 9
## Suitability of Native Soil Types as Cover

| | Gravel | Sand | Silt | Clay |
|---|---|---|---|---|
| **Health Considerations** | | | | |
| Infiltration | − − | − − | + | + |
| Erosion | + + + | + + | − − | + |
| Gas | + + + | + + | + | − − |
| Fires | − − | + | + + | + + |
| Flies | − − | − − | + | + + |
| Rodents | + + | + | − − | − − |
| Birds | + | + + | + + | + + |
| **Aesthetic Considerations** | | | | |
| Blowing Paper | + + | + + | + + | + + |
| Noxious Odors | − − | + | + + | + + |
| Appearance | + | + + | + + | + + |
| **Site Use Considerations** | | | | |
| Vehicle Support | − − | + + | + | − − |
| Workability | + + + | + | − − | − − |
| Vegetation | − − | + | + + | + |
| End Use | − − | + | + + | + |
| **Other Considerations** | | | | |
| Wind Erosion | + + + | + + | + | − − |
| Dust | + + + | + + | + | − − |
| Cold Weather | + + | + | + | − − |
| Slope Stability | + + | + + | − − | + |
| Cracking | + + + | + + + | + | − − |

+ + + Excellent
+ + + Excellent
+ + Good
+ Fair
− − Poor, or completely unacceptable

Slope stability and cracking can be a problem when it comes to clay. The coarser materials are superior.

## SOIL BLENDINGS

As an alternative to using a single soil type for a cover application, blendings of various soils may serve to provide appropriate controls at both ends of the spectrum (e.g., resist cracking, minimize infiltration, while at the same time allowing some degree of gas venting). Soil blendings increase the expense of covering the waste, and therefore, have not usually been considered in previous landfill designs. However, the benefits derived from blending are sometimes so dramatic through the alteration of grain size distribution and average grain size, that they deserve serious attention in the future.

Well graded soils have relatively low **hydraulic conductivity (k) values,** and are desirable for the purpose of minimizing infiltration. If well graded soils are not available nearby, but coarse and fine grain soils are, blending may provide an acceptable product besides an increased source of supply. The procedure is effective only for increasing impedance to water movement since a broadening of the grain size distribution almost always results. Blending may be accomplished in-place, using a blade or harrow.

The effects of gravel additions on permeability have been measured in the laboratory. Tests reveal that k values drop with the addition of gravel to sand to about one-seventh of the value of sand alone. This effect remains about the same over the range of gravel contents of 20 to 60 percent. For mixtures containing more than 65 percent gravel, k increases again because the sand is unable to fill the space between the pebbles. Obviously the addition of gravel would be acceptable only under certain circumstances and is usually not desirable due to the probability that infiltration to the refuse mass will be increased.

Sand and silt additions can prove beneficial to cover materials where the grain size effectively supplements the distribution of grain size in the natural soil, especially where reduced percolation is desirable. Strength is also enhanced upon compaction. Other benefits from the addition of sand consist of potential savings in spreading and compacting costs where the original soil is clay rich and, therefore, sticky or slippery when wet. Granular materials may also serve to condition certain soils to support vegetation.

The addition of clay to soils produces a particularly dramatic reduction in k values. Certain operational difficulties should be expected with clayey soils which tend to contain considerable water, and therefore, consideration should be given to the fact that it is likely these soils will experience increased difficulty in handling. It may be appropriate to excavate blending clays during relatively dry spells, storing them and incorporating them during favored times of the year. Harrowing will usually be necessary. Elsewhere, it may be advantageous to use commercially available clay. Sacked bentonite should be available at modest cost in dry form suitable for rapid and inexpensive incorporation. Each case will have to be evaluated for cost and the desired beneficial effects.

## SOIL ADDITIVES OR CEMENTS

This category has been subdivided into two types: *1. cemented soils, 2. modified soils.* Cemented soils are meant to include cement-soil mixtures and bitumen-soil mixtures. Modified soils are meant to include cement treated soils, lime treated soils, and various fly ash additives (including fly ash and lime treated soils, fly ash treated soils alone, and fly ash lime sulfate treated soils).

In contrast to the non-soil covers or membrane liners to be described subsequently, additives and cements are defined as synthetic materials added in relatively small amounts to soil to achieve beneficial effects. Factors that enter into determining the cost-effectiveness of additives and cements are their relatively high unit costs, manner of addition or incorporation, and duration of effect. A major concern in using any cover system with increased strength is the remaining susceptibility to cracking as a result of differential settlement or environment deterioration such as freeze-thaw cycles. Plans for patching and other repairs are essential.

## NON-SOIL COVERS AND MEMBRANE LINERS

Non soil-covers or membrane liners can be divided into five types:

- *portland cement materials*
- *asphaltic materials*
- *soil sealants and liquid spray rubber*
- *synthetic polymeric membranes*
- *waste materials*

Portland cement concrete or mortar ordinarily should be placed on a well compacted base. This requirement and the high cost of portland cement makes concrete unattractive for use over municipal and other soft solid waste that will settle subsequently. Reinforcing steel bars do not materially improve the integrity except to reduce separation after cracking, and it should be noted that steel can increase costs by about 15 percent.

Asphaltic materials have been identified as including:

- *bituminous concrete or mortar*
- *bitumen-sulfur concrete*
- *sprayed bituminous membrane*
- *reinforced bituminous membrane*
- *prefabricated bituminous membrane*

Asphaltic materials provide tight, impervious barriers capable of covering either municipal or hazardous waste landfills. Availability is good. In addition, they may be used as thick waterproofing in flat areas or on slopes. However, they are relatively expensive, can be vulnerable to breaking and cracking, and require special heating and storage equipment.

Soil sealants and liquid sprayed rubber may include:

- *rubber and plastic latex*
- *penetrating polymeric emulsion*
- *polyurethane foam*

These materials may be sprayed on soil covers to decrease water and gas permeability. Alternatively, they may be mixed with soil to form a waterproof layer. If applied properly, they can provide hard, tight, stable membranes. The sprayed surface must be exposed until it either cures or sets. Membranes usually must be cov-

ered for protection. Often they require additional equipment to handle and apply. Also, spraying temperatures may range from 75° to 270°F. Lastly, a thick membrane may require numerous applications.

Synthetic polymeric membranes include:

- *polyvinylchloride (PVC)*
- *polyethylene (PE)*
- *chlorinated polyethylene (CPE)*
- *chlorosulfonated polyethylene (Hypalon)*
- *butyl rubber*
- *ethylene propylene rubber (EPDM)*

Synthetic polymeric membranes are available in various sizes and configurations. They may be reinforced with fibers for added strength. They can be joined at the seams to cover large areas. They have good availability, good heat resistance, very low water permeability, and low vapor transmissivity. On the other hand, they may be relatively expensive. They often provide poor resistance to weathering and abrasion, and they may be damaged by burrowing animals if not protected with soil. Lastly, they may be damaged by heavy equipment operating directly on the surface and may be punctured by large stones or sharp edges and sharp contact. Of course, the possibility of reactivity of polymeric membranes with hazardous wastes (or the hazardous constituents and leachates from municipal wastes) needs to be addressed in every case.

The last category of non-soil covers is waste materials. Waste materials may include:

- *fly ash*
- *bottom ash and slag*
- *incinerator residues*
- *foundry sand*
- *mine and pit wastes*
- *mine mill tailings*
- *plant sludges*
- *dredged materials*

Although much has been discussed about the suitability of these waste materials for landfill cover, little is known about their actual performance in the field. Obviously their high availability in certain industrialized areas, combined with their apparent suitability for landfill cover (i.e., small particle size) makes them excellent candidates for at least some further investigation.

*COSTS OF LANDFILL COVER MATERIALS*

Table 10 has been included as a summary of the estimated relative cost for selected landfill covers. It should be noted that most of the material included in this table is dated by at least three to four years at this point. Although it can be particularly expected that the costs of synthetic membranes have risen appreciably in recent years, accompanying the increase in petroleum costs, this table provides a good assessment of the relative costs of various liner materials. These costs should be weighed in conjunction with the technical advantages and disadvantages stated previously before any landfill designer proceeds to specify a given cover material.

I would now like to describe briefly one of the projects my company has been involved with. The facility is the landfill at Windham, in east central Connecticut, and the study, conducted by the USEPA, is still ongoing.

The landfill was in operation from 1945 to 1978. It contains two sections, a ten-acre area, which received waste from 1945 to 1960, and a fifteen-acre area, which received work from 1945 to 1978. Contaminant plumes were detected by the town a long time ago, heading westward, toward a water supply reservoir. This was very well documented, and provided a base line for the beginning of demonstration projects. I might mention that the landfill was located in a sand and gravel quarry. Investigations in 1978 and 1979 determined that 85 percent of the leachate was being generated by infiltration, as opposed to groundwater moving into the fill. The east side of the ten-acre area was actually in groundwater.

Remedial action was carried out on the ten-acre pile, starting in 1979. First, four inches of sand were laid down, followed by a PVC liner, and then eighteen inches of fine sand and gravel. Finally, the covered area was planted with vegetation. Monitoring since remedial action was taken is continuing, and the jury is still out on whether it will be totally effective. However, the plume has already perceptibly regressed, and the results look very good.

**Mr. Murdock:** Lawrence Murdock, Southold Township. Assuming that we go into a resource recovery program for municipal solid waste, are you saying that maybe we could cover our existing landfill with fly ash?

**Mr. Walsh:** I think that's a definite possibility. However, it depends. You're talking about the flue particles opposed to the incinerator residue, the bottom ash?

**Mr. Murdock:** Well, either way. We have both.

**Mr. Walsh:** Both have been proposed for this purpose. In the past, there have been investigations into the use of fly ash. I don't believe there has been any investigation into the use of incinerator ash. Generally, incinerator ash is going to have smaller particle sizes and it depends on the particle size. It certainly has been proposed.

**Mr. Lappano:** Paul Lappano, H2M. In that particular landfill that was capped with a PVC liner, did you have problems with methane gas migration?

**Mr. Walsh:** It's my understanding the answer is no. There was an airport immediately adjacent to this that would definitely be a concern, but there wasn't a problem there.

**Mr. D'Antonio:** Bill D'Antonio, North Hempstead, Long Island. You mentioned before that one problem could create another one. We, in New York, particularly in D.E.C. Region One, have a requirement that our landfills be capped. Can you relate that to other problems that it might create?

**Mr. Walsh:** I was trying to play one off on the other. The most important was the gas migration problem. That does not mean that if you cap the landfill, you're necessarily going to have gas migration problems. The Connecticut landfill was a good example. However, the State still requires a cap and you may have to install gas control measures, either passive or active venting.

28

# TABLE 10

## Estimated Relative Costs For Selected Landfill Covers

| Cover Type and Thickness | Cost ($/sq.yd.) |
|---|---|
| **Native Soil and Soil Blending** | |
| Loose Soil (2 ft.) | $0.35 |
| Compacted Soil (2 ft.) | 0.70 |
| **Additives and Cements** | |
| Bentonite Admixture (9 lbs./sq. yd.) in Soil | $0.75 |
| Soil - Cement (7 in.) | 1.50 |
| Soil - Asphalt | 1.50 |
| **Non-Soil Covers** | |
| Bentonite Layer (2 in.) | $1.40 |
| Cement Concrete (4 in.) | 9.00 |
| Asphalt Concrete (4 in.) | 3.00 |
| Paving Asphalt (2 in.) | 1.45 |
| Sprayed Asphalt Membrane (1/4 in.) and Soil Cover | 1.50 |
| Reinforced Asphalt Membrane (100 mil) and Soil Cover | 1.75 |
| Polyvinylchloride Membrane (10 mil) | 1.25 |
| Chlorinated Polyethylene Membrane (20-30 mil) | 2.80 |
| Hypalon Membrane (20 mil) | 2.50 |
| Ethylene Propylene Rubber Membrane | 3.10 |
| Butyl Rubber Membrane | 3.25 |
| Neoprene Membrane | 5.00 |

**Mr. Wolterding:** Dennis Wolterding, DEC. You mentioned, what would certainly be logical, that sand areas are the best for maintaining migration in terms of the fact that you get venting.

In fact, though, our experience over the last three years is exactly the reverse. Sand areas seem to prevent migration better than areas of clay. I believe the reason might be because of the high moisture storage capacity. Fine grained materials retain water and so effectively that they're saturated or near saturation.

**Mr. Walsh:** I think, Dennis, we've encountered similar situations to what you described. Many of our gas migration projects have been on landfills located in sand and gravel quarries.

We've generally encountered non-homogeneous soils. You have silty sand and silty clay on the surface and more porous materials as you go down. The gas is trapped below the surface, not even under the landfill, but adjacent to it, therefore forcing migration.

I didn't mean to say that if you use the native soil, and those are the sands you'd find around here, that you're going to be without gas migration problems. It's a concern.

29

*SELECTED REFERENCES ON LANDFILL CAPPING*
The following is a selected list of references available on the subject of landfill capping. If further information on this subject is desired, it is suggested that the reader refer to these documents. Most of these reports can be obtained through the **Solid Waste Information Services of the U.S. Environment Protection Agency.** Alternatively, all reports are available through the **National Technical Information Service in Springfield, Va.**

1  *Design and Construction of Covers for Solid Waste Landfills*
   U.S. Army Engineers Waterways Experiment Station
   U.S. EPA Report No. EPA-600/2-79-165

2. *Solid Waste Landfill Design and Operation Practices*
   SCS Engineers
   Soon-to-be-published U.S. EPA report

3. *Guidance Manual for Minimizing Pollution from Waste Disposal Sites*
   A.W. Martin and Associates
   U.S. EPA Report No. EPA-600/2-78-142

4. *Manual for Closing or Upgrading Open Dumps*
   SCS Engineers
   Draft U.S. EPA report

5. *Evaluating Cover Systems for Solid and Hazardous Waste*
   U.S. Army Engineers Waterways Experiment Station
   U.S. EPA Report No. SW-867

6. *Lining of Waste Impoundment and Disposal Facilities*
   Matrecon, Inc.
   U.S. EPA Report No SW-870

7. *Top Sealing to Minimize Leachate Generation—A Status Report*
   A.W. Martin and Associates
   From Proceedings of the Seventh Annual U.S. EPA Solid Waste Symposium
   U.S. EPA Report No. EPA-600/9-81-002b

# Establishing Vegetation on Landfills

TERRY SCHNADELBACH

R.T. Schnadelbach Partnership, New York, N.Y.

## ABSTRACT

*Landfills are characterized by a unique assemblage of plants in relation to surrounding areas. Surface temperatures of landfills can reach 135°F as a result of internal decomposition. These elevated temperatures discourage germination of many deciduous plant seeds. A paucity of available nutrients, an absence of proper soil layers and a lack of symbiotic soil bacteria prevent many plants from colonizing landfills. Some plants, however, collectively termed **pioneer** plants, can establish themselves on landfills. A cover of vegetation reduces erosion and percolation into groundwater and serves to stabilize the land form. A landfill can be conceptually divided into three parts in reference to planting design considerations: 1) side slopes, 2) top zone and 3) bottom edges and adjacent area. The uppermost area of a slope should be vegetated with plants capable of rapid water absorption and drought tolerance to exploit periodic rains that run off rapidly. Side surfaces should be planted with fire-resistant species because fires caused by methane leakage do occur. The bottomlands should be planted with species that tolerate high water concentrations since runoff from the slopes tends to collect in these areas. Between 30-50 percent of runoff can be absorbed by grasses and between 60-80 percent by shrubs/trees. **Marsh grasses** have the ability to capture silt and absorb high concentrations of water-borne pollutants; **Phragmites** can absorb large quantities of lead and break down PCB's. Planting a windbreak on the bottomlands on the windward side of the pile can reduce erosion. Capping a landfill with sand and gravel permits the establishment of trees and shrubs which serve to rapidly absorb rainfull; these soils also allow gas and vapors to percolate through the landfill surface.*

By now everybody is just about squirming in their seats with information overload, as we've gotten rather technical and we've moved along quite fast. We have breathed the same stale air for the last two or three hours, and we've been daydreaming about what a wonderful day it is outside. It's a number ten on a scale of one to ten.

On the way into the seminar this morning we probably saw the first signs of fall and autumn colors coming in. The sumac trees are beginning to turn slightly red at the tip, as are the flower stalks, seed stalks whose ends have started to become really red. The grasses have turned brown or shades of tan russet and have gone to seed. Probably, along the way, we spotted the poplars that have turned slightly yellow with the first turn of fall.

If I had my choice, I would rather be outside, in a natural environment, breathing fresh air and not talking about landfills and their problems, of garbage dumps and such unsightly messes.

I would like to be watching the first migration of the butterflies that are coming through Long Island right now and thinking environmental and ecological thoughts. But, alas, we're here, and if I am going to talk about planting on landfills and garbage dumps, I would like to do it in a way that is environmentally sound. I would like to talk about it in a way that addresses every use potential.

We can talk about well-designed landfills, with slopes that were properly sealed, properly capped, properly graded for erosion control, properly designed so that stormwater won't pollute our aquifer or groundwater supply or run off into the local bays. But in order to make the point clear, I wouldn't have picked that finished product to show you the planting that would be best suited for it. Instead, I would take you to an active garbage dump, as I take my classes wherever I've taught.

Yes, it's smelly and you can see roaches and rats and other kinds of animals, and not butterflies, and we can see the contrast between what used to grow there and the things that are growing there now. They're not barren wastelands. Things have volunteered to come into that area, both animals, and plants. We call them volunteers. They're pioneers and volunteers on a wasteland, and they feed themselves and grow prolifically.

They're not plants that we're used to seeing, such as pine. You won't find a pine tree in a garbage dump. You'll not find a peach tree and you won't find oaks. The water regimen in these landfills and on these sites doesn't allow those plants to find a natural habitat to germinate, to seed freely, so if you're going to talk about rehabilitating these sites, providing a vegetative cover, and, perhaps, a future land use afterwards, that's something to consider.

Recreation and some housing have been placed on them, as well as industrial developments. If that's the case, then we should talk about their after-use and the vegetation that is best suited to colonizing the land, and I'd be talking about trees like *ailanthus, honey locusts and black locusts*. That was a wonderful tree that was imported in the 1931 World's Fair and has colonized most of the eastern seaboard.

These plants are a very realistic part of our environment, just as the seasons change, and they make our scars on the face of the earth, our landfills, more habitable and also more safe and usable thereafter in the environment.

The reasons we find different plants on landfills and garbage dumps have to do with the internal conditions of the refuse mass. For instance, it's very hard for normal woody, forest-type trees to come in, because the temperature on a landfill mass is much higher than in a normal environment. Seed colonization and germination really become quite difficult. They burn out very rapidly. Sometimes the surface temperatures will reach 125 to 135 degrees, because of the internal heat of decomposition.

We'll also find a lack of usable nutrients, a lack of proper soil layers, a lack of bacteria that will colonize certain plants and help germination. These just aren't present, and plants are really trying to grow in basically raw materials such as lead, sulphur and other kinds of things that have been deposited there, even if in many cases they have been covered with three feet of soil.

So, we really have to start taking a look at the volunteer plants, not only big trees, but plants such as wild roses or knot weed. There are also bushes that are edible, such as staghorn sumac, which I mentioned before.

It can produce a wonderful lemonade-type tea. You can also find some kinds of grasses usable in salads.

I'd like to talk briefly about some of the reasons for planting a landfill. As was mentioned before by Mr. Walsh, we want to reduce erosion, and percolation into groundwater. Another reason for the use of plant material is to promote the internal stability of the land form. As the material decomposes inside, various changes can occur on the top surface. We may start with a positive slope gradient on the top, but over a period of years sinks can occur, in which water collects. If there is no vinyl cover, but only a layer of sand, water can percolate through the soil cover, into the landfill, and we will have the problem of leachate. So that with the proper planting of a tree mass, a more even fibrous root can be developed, which will help stabilize areas and help control internal sinks. In dealing with planting on a particular site, there are several physical problems that have to be addressed. Basically there are three parts to any landfill pile. Each needs to be taken into account, and special design consideration should be applied to them.

First, and very obvious, are the side slopes. Many of them are graded quite steeply. Then, there is the flat or topped area of a site. Finally, there are the bottom edges and the area adjacent to the pile, where stormwater collects, and leachate begins to percolate out. The side slopes and the bottom slopes are also very susceptible to migration of methane gas as it builds up in the fill.

Figure 17 is a rough diagram of a section through a landfill site. I mentioned the sloped area. The bottom zone will have side swales. There is a need for small earth berms for the control of surface water runoff and
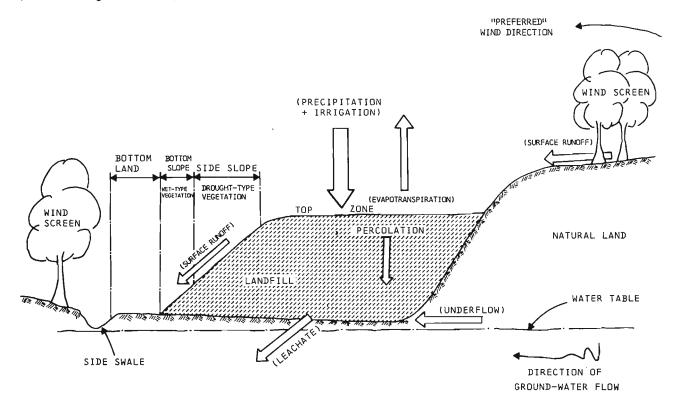


Figure 17  *Landfill characteristics*

perhaps leachate. Lastly, there is the top zone itself.

The topmost area of a slope really should be planted with material that is very drought resistant. It should be a plant material similar to that found in the upper head waters of a watershed area, where rain hits and runs off at a very rapid rate. This area has to absorb water very, very rapidly and then go through periods of extensive drought. The soils, whether they be sands, clays and so forth would tend to shed water rapidly and thus return the area to prevailing drought conditions.

This morning, I was talking to a fire chief here on Long Island, about the occurrence of fires on landfill sites, even when they have been capped. The type of plant material that is selected at such a site should be very resistant to fires and be a kind of plant different from what is seen in pine barrens.

Generally, the drought zone on a slope area is roughly the upper two-thirds. The bottom slope should be planted with water-tolerant plants, ones that can accept the huge quantities of water that move down the slope, as well as a lot of the moisture which moves laterally through the landfill and seeps out at a very gradual rate. The type of plants selected for this area should be able to absorb chemical toxins and convert what might be a primary chemical into an organic compound through decomposition. The toe of the slope is the most important part for controlling erosion.

Lastly, there is the bottomland and the bottomland treatment. Plants within this area can control water runoff very effectively. By planting grasses, we can absorb between 30 and 50 percent of water runoff. By planting shrubs and trees, we can control between 60 and 80 percent of the runoff on a site through revegetation and restoration. Grasses in the lowlands are very important, because many of them can also capture silt and can very rapidly absorb water-borne pollutants. The ability of marsh grasses, for example, to accept high rates of nutrients and receive water is well known and well documented. Consider the plant phragmites. That's an ancient plant of the Nile and Euphrates Rivers. The ancient Egyptians used it as their major channel liner and major waste water treatment method. Several artifacts have been found of actual sewage treatment facilities, that were nothing but simple pits planted with phragmites. Phragmites is one of the few plants in the environment that can actually begin to break down PCB's that plague some waterways. It can also absorb large amounts of lead. Planting a windbreak in the bottomland area will have the beneficial effect of reducing erosion. Most erosion occurs on the windward side of the refuse pile, because rain strikes hardest there. A windbreak, therefore, not only protects against wind erosion, but directs wind-borne rain higher over the mass, and gives a more even distribution of water over the top surface.

The planting on top is the last part of the land form itself. Here we get into quite a difference of opinion as to whether it should be planted or not. For instance, the fill may be capped with bentonite. Bentonite, as indicated earlier, is a material which swells. It would be very difficult and probably disadvantageous to plant trees on such caps, even with a cover of some natural, indigenous soil on top. The liner could be broken by roots, although, admittedly, it would expand back.

It would probably be better in this case to plant a series of grasses of various types that would colonize the upper surface and assist in the control and uptake of water.

Other kinds of soils, such as the sands and gravel that we have talked about, could actually be much better cap materials. They permit revegetation or reforestation of trees and larger plant material, which take up rainfall instantly and capture it in the upper surface rather than let it pass through. At the same time, these soils allow gas and other vapors to breathe out through the landfill site itself.

There are a lot of examples where the proper design of all three parts of a landfill surface have produced very usable landscapes, very usable urban parks, and some of them are in New York State. I've not seen any here in Suffolk or Nassau County, but I know about several in the Albany area and upstate New York, around Niagara Falls. There is a parking lot in the City of Niagara Falls built on top of an old landfill. In the wintertime there's tobogganing and sleighing. In the summertime there's football games and other kinds of activities on it. They have picnics on top of the site.

**Mr. Watson:** Dick Watson from Brookhaven. Can you give us any idea of what fraction of precipitation you think you'll have percolating down, what fraction of precipitation you hope to prevent from percolating?

**Mr. Schnadelbach:** If I was just using plant material and not considering the soil as mentioned before?

**Mr. Watson:** Right.

**Mr. Schnadelbach:** I would want to control 50 to 60 percent of the surface water hitting the site, just through the plant material itself. Then, in combination with soil, I think we should be hitting pretty close to controlling 90 to 100 percent.

**Mr. Watson:** What's the most cost effective cover material for its ability to support vegetation, or the most cost effective way to evaluate the material. Sometimes the origins of cover material are doubtful.

**Mr. Schnadelbach:** The very same leachate tests that are being performed on the landfill site itself, or on the open dump, will give us a chemical analysis for the material itself. That, coupled with several vertical bores through the site will give an idea of the compaction of material.

From that we usually use a rule of thumb method to predict the required mass stabilizing rate, the required root level and root structure, and the required plant temperature for germination. From there you begin to formulate a plant list for the most effective control.

The best way, the most simple and practical way, that we've had the best success with, is to start out using the plants that we actually find growing on the sites. They produce the most rapid growth and germination and produce the most dense cover. We have had the least amount of die out of revegetation by planting from them.

# Landfill Closure and Erosion Control

JEFFREY VONK

USDA, Soil Conservation Service, Riverhead, New York

## ABSTRACT

*The upper surface of a landfill should be graded to provide a positive gradient from the center to the edges. A crown of terraces or diversions should be constructed to intercept runoff and direct it to vegetated or lined waterways which in turn direct water to natural water courses, recharge basins or large, level areas. Side slopes of 3:1 allow relatively easy establishment of vegetation; steeper slopes are more difficult to vegetate and encourage gully erosion. Vegetation provides the protection landfills need against cracking, subsidence and erosion. Surface soils should be tested to determine the composition and quantity of fertilizer needed. Various seed mixtures including grasses and légumes are recommended for application. Light mulching is important for establishing vegetation on critical areas. Seeds may best be sown by drilling and hydroseeding on level and steeply sloping surfaces, respectively; broadcasting by hand is another method.*

Many of the landfills currently in operation on Long Island present difficult problems to those concerned with final closure. Among these problems are those of stormwater management and erosion control. This paper will briefly address some of the aspects to be considered when a capping design is being prepared.

Ideally, a plan of operation for a sanitary landfill will have considered all aspects of capping before operation begins. This advance planning would pay large dividends in the end in that many of the problems faced by the operators at the time of closure would be avoided. However, in most cases, without prior planning, we find ourselves near the end of the lifespan of a landfill and are faced with developing a plan for closure that will meet both State standards and provide for long term stability.

## PHYSICAL ASPECTS—LANDFILL CLOSURE

Logic dictates that the landfill surface be graded in such a manner as to provide a positive gradient from the center of the landfill to the edges. This will allow surface water to flow to the sides of the landfill and away from the site, thereby reducing the leachate problem. It should not be too difficult to create, on top of the landfill, a large crown or series of small crowned areas with waterways between them which will allow the surface water to flow toward the edges of the landfill. The most difficult problems of runoff water management occur on the sides of the fill sites.

In most cases, we are talking about relatively steep side slopes which need to be protected and stabilized. Whenever possible, we would recommend that these slopes be graded to no steeper than 3:1. Side slopes of 3:1 or flatter allow for relatively easy mechanical establishment of vegetation and lend themselves to easy maintenance in the future.

When side slopes are steeper than 3:1, or the length of slope exceeds 100 feet, some types of structural erosion control/water management practice should be installed. In most cases, this might be a series of terraces or diversions (Figure 18.) designed to safely handle the runoff from a 2 year frequency storm (3.5 inches of rain in a 24 hour period in Suffolk County). These would be constructed across the slope with a slight grade (approx. 1-2%) and would serve to intercept runoff moving down the side slope of the landfill. The object is to space these diversions to intercept the runoff water before it attains too great a velocity or concentrated volume and therefore causes a gullying problem. The spacing on each site will be determined by the length and steepness of the respective slopes.

These diversions or terraces will discharge into either vegetated or lined waterways which are designed to conduct the water safely to the bottom of the landfill.

CROWNED TOP

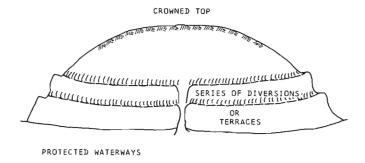SERIES OF DIVERSIONS
OR
TERRACES

PROTECTED WATERWAYS

Figure 18  Erosion control/water management structure

The waterways will also be sized depending on the amount of water to be emptied into them. All engineering firms have the information to design and properly size these structures based on storm frequency and drainage area involved.

Once the runoff water has been safely conducted to ground level, it can be diverted to natural watercourses, recharge basins, or, space permitting, allowed to spread over a large, level area until dissipated.

Depending on the size and existing topography of the landfill, this type of mechanical treatment for runoff water management may be applied as separate parts on individual sections of the landfill or may be designed as a single system to treat the entire landfill area.

## VEGETATIVE ASPECTS—LANDFILL CLOSURE

Once the mechanical runoff control measures are installed and final grading has been completed, it is imperative that a good, protective vegetative cover be established on the entire landfill area. Particular care should be taken to follow all the agronomic steps necessary to insure a good catch of whatever seed mixture is used. To cut back on this aspect of the landfill closure operation is to risk a poor seeding and, therefore, the protection of all the operations that preceeded the seeding. Vegetation provides the protection that the landfill needs and without a good stand, future problems with cracking, subsidence and erosion will occur.

## SITE AND SEEDBED PREPARATION

A series of soil tests should be taken to determine the lime and fertilizer needs. This is very important as most Long Island soils are very acidic in nature and require significant amounts of lime to bring the pH to a suitable level. All debris such as tree stumps, roots, large stones, etc. should be removed from the soil surface.

Scarify the surface to a depth of at least 2 inches with a disk or other suitable equipment. Apply lime and fertilizer according to the soil test, or based upon the needs of the soil. Mix them into the surface soil to a depth of at least 2 inches. If lime and fertilizer are applied by hydroseeder, incorporation into the soil is not practical.

The following are suggested application rates for permanent seedings:

1. Apply the amount of lime needed to attain a pH of at least 6.0 if legumes are included in the seeding mixture. If only grasses are to be seeded, a pH of 5.5 is acceptable.

2. Apply at least 30 pounds of nitrogen and 60 pounds each of phosphorous and potassium (600 pounds of 5- 10- 10 or equivalent) per acre.

3. Where possible, lime and fertilizer should be incorporated into at least the top 2 inches of soil by disking.

## SEED SPECIFICATIONS

Whenever available, certified seed should be used. Legumes should be scarified if necessary and inoculated with the proper strain of nitrogen-fixing bacteria before seeding. Use only strains adapted to local climatic conditions. The following are possible seed mixtures that should work well on landfill sites:

| a) Switchgrass | 5 | lbs/ac |
|---|---|---|
| Bluestem | 5 | |
| Perennial ryegrass | 5 | |
| Birdsfoot trefoil | 5 | |
| | 20 | lbs/ac |

| b) Tall Fescue | 20 | |
|---|---|---|
| Flat Pea | 30 | |
| | 50 | lbs/ac |

| c) Deertongue | 10 | |
|---|---|---|
| Birdsfoot trefoil | 8 | |
| Perennial ryegrass | 3 | |
| | 21 | lbs/ac |

| d) Deertongue | 10 | |
|---|---|---|
| Crownvetch | 15 | |
| Perennial ryegrass | 3 | |
| | 28 | lbs/ac |

For seeding the diversions and waterways the following mixture has been shown to be effective:

| Creeping red fescue | 20 | |
|---|---|---|
| Redtop | 2 | |
| Tall fescue | 20 | |
| | 42 | lbs/ac |

## TIME OF SEEDING

Good results are usually attained from seeding or plantings that are done in the spring before May 15 or in the late summer after August 10. Spring seeding legumes is recommended. However, late summer seedings prior to September 1 can also be made. When crownvetch is seeded in late summer, at least 35 percent of the seed should be hard seed (unscarified).

Temporary seedings of annual ryegrass or spring oats, or a combination of them, may be made at any time

36

during the early or mid-spring season. Sudangrass or annual ryegrass or winter grains may be used for late summer and fall temporary seedings.

Temporary seedings of spring grains and annual ryegrass may be made in August. Permanent seedings of perennial grasses and/or legumes may then be overseeded in the spring. For other temporary seedings, where regrowth is desired in the spring, winter hardy grains or perennial ryegrass may be seeded in August or early September.

## MULCHING

Mulching is a very important step in establishing vegetation on critical areas. A mulch cover will help to hold moisture, protect soil from erosion, hold seed in place, and keep soil temperatures more constant. It should be applied uniformly by mechanical means or by hand. Some bare soil should still be visible through the mulch. Too heavy an application in the spring may retard the soil warm-up rate.

Hay or straw or other fibrous mulches are best for mulching newly seeded areas. Some of the mulches are subject to blowing and must be kept moist or tied down.

Mulch materials may also be used alone as a temporary ground covering measure for minimizing soil erosion.

Hydromulching is a process by which water and various combinations of seed, fertilizer, pulverized limestone, inoculants, wood cellulose and even compatible insecticides and fungicides are mixed in a tank to form a **slurry**. The slurry is held in suspension by continuous agitation. The material is sprayed over the area to be seeded, under high pressure. Wood cellulose mulch is suitable only in a slurry. It cannot be used for dry applications.

See Table 11 for a guide to mulching materials, rates and uses, and Table 12 for mulch anchoring.

## SEEDING OR PLANTING

*Drill*—A grass drill is the best method of seeding on nearly level to sloping areas, but the preferred method will depend on slope and conditions of the planting site. Very small seed must be seeded no more than 1/4 to 1/2 inch deep. If the drill does not have a packer attachment, a packer should be trailed behind it. On steep slopes, where drilling is not feasible, hydroseeding is an alternative method.

*Hydroseeder*—This method is best for steep, inaccessible areas where a drill is difficult or impossible to use. When applying seed, lime, fertilizer or mulch materials with the hydroseeder, do not use more than 100-150 pounds of solids per 100 gallons of water. A low pH is detrimental to the legume inoculant. If the inoculant is in a seed/fertilizer/lime slurry, it should be used within 3-4 hours, or a fresh supply of inoculant should be added.

When Legume seed is to be included in a slurry mixture containing fertilizer, the amount of inoculant added to the tank should be four times the rate prescribed by the manufacturer.

If legumes are not included in the seed mixture, the seed may be mixed in a slurry with the lime and fertilizer. Hydrated lime should not be used when seed is mixed into the slurry.

It is preferable to hydroseed when the soil is moist.

*Broadcast*—Seed may be broadcast by using a whirlwind or cyclone seeder, or by hand. If spread by hand, seed may be mixed with sawdust to help achieve an even distribution.

One half of the seed should be applied by walking in one direction, and the other half by walking in a direction 90 degrees to the first direction. This yields a much more uniform seeding with fewer missed areas. Cover seed with 1/4 inch of soil or less by cultipacking or raking, or other suitable method.

## MAINTENANCE

*Fertilization*—When seedings or plantings consist only of grasses, nitrogen fertilizer should be applied annually at the rate of about 40 pounds per acre, or 1 pound per 100 square feet. A complete fertilizer should be applied if there is reason to believe that phosphorus and potassium are not adequate. If a soil test can be obtained, fertilizer should be applied as tests indicate. Where legumes are included in the plantings, nitrogen applications are usually not necessary.

## NOTE

If there are any questions about any of the material in this paper, we can be contacted at:

Soil Conservation Service
127 East Main Street
Riverhead, New York 11901

Much of the above information is available in the Soil Conservation Service publication: **A Guide to Conservation Plantings on Critical Erosion Areas, SCS, Syracuse, N.Y.**

## TABLE 11
## Guide to Mulch Materials, Rates & Uses

| Mulch Material | Quality Standards | Application Rates per 1000 Sq. Ft. | per Acre | Depth of Application | Remarks |
|---|---|---|---|---|---|
| Sawdust, Green or Composted | Free from objectionable coarse material | 83-500 cu. ft. | -- | 1-7" | Most effective as a mulch around ornamentals, small fruits, & other nursery stock. Special application rates: fruit trees 5-7"; blueberries 6"; vegetables and flowers 2-3"; blackberries and raspberries 4-7"; strawberries 3". Most resistant to wind blowing. Requires 30-35 lbs. N/ton to prevent N deficiency while decaying mulch. One cu. ft. weighs 24 pounds. |
| Wood Chips or Shavings | Green or airdried. Free of objectionable coarse materials | 500-900 lbs. | 10-20 tons | 2-7" | Has about the same use and application as sawdust, but requires less N/ton (10-12 lbs). Resistant to wind blowing. Decomposes slowly. |
| Wood Excelsior | Green or airdried burred wood fibers .024" × .031" × 4" | 90 lbs. (1 bale) | 2 tons | -- | Effective for erosion control. Tie-down usually not required. Decomposes slowly. Subject to some wind blowing. Packaged in 80-90 lb. bales. |
| Wood Fiber Cellulose (Partly digested wood fibers) | Made from natural wood usually with green dye & dispersing agent added. Max. 15% moisture packed | 50 lbs. | 2000 lbs. | -- | When used for erosion control on critical areas double application rate. Apply with hydro-mulcher. No tie-down required. |
| Compost or Manure | Well shredded, free of excessive coarse material | 400-600 lbs. | 8-10 tons | -- | Use strawy manure where erosion control is needed. May create problem with weeds. Excellent moisture conserver. Resistant to wind blowing. |
| Jute, Twisted Yarn | Undyed, unbleached plain weave. Warp 78 ends/yd Weft 41 ends/yd | 48" × 50 yds or 48" × 75 yds | Roll 60 lbs. 90 lbs | 60 sq yds 100 sq yds | Use without additional mulch. Tie down as per manufacturing specification Effective for erosion control on critical areas. |
| Excelsior Wood Fiber Mats | Interlocking web of excelsior fibers with mulch net backing on 1 side only. | 36" × 30 yds. | Roll | 16-½ sq. yds. | Use without additional mulch. Tie down as per manufacturing specifications. |
| Glass Fiber | 1/4" thick, 7/16" dia., holes on 1" center. | 72" × 30 yds. | Roll 56 lbs | 100 sq. yd | Use without additional mulch. Tie down with T bars as per manufacturing specifications. |
| Plastic | 2-4 mils | Variable up to 50' wide | | | Use black for weed control; use white for seeding establishment without organic mulch. Release plastic after seeding is established. Effective moisture conservation and weed control for small fruits. |

38

## TABLE 12
## Mulch Anchoring Guide

| Anchoring Method or Material | Kind of Mulch to be Anchored | How to Apply |
|---|---|---|
| **A. Manual** | | |
| 1. Peg and Twine | Hay or straw, pine straw | After mulching, divide areas into blocks approx. 1 sq. yd. in size. Drive 4-6 pegs per block to within 2" to 3" of soil surface. Secure mulch to surface by stretching twine between pegs in criss-cross pattern on each block. Secure twine around each peg with 2 or more turns. Drive pegs flush with soil where mowing & maintenance planned. |
| 2. Mulch netting | Hay or straw, shredded sugar cane, pine straw, compost, wood shavings, 'tanbark' | Staple with light-weight paper, jute, wood fiber, or plastic nettings to soil surface according to manufacturer's recommendations. |
| 3. Soil & stones | Plastic | Plow a single furrow along edge of area to be covered with plastic, fold about 6" of plastic into furrow and plow furrow slice back over plastic. Use stones to hold plastic down in other places as needed. |
| 4. Silt | Hay or straw | Cut mulch into soil surface with square-edge spade. Make cuts in contour rows spaced 18" apart. |
| **B. Mechanical** | | |
| 1. Asphalt spray (emulsion) | Compost, wood chips, wood shavings, hay or straw | Apply with suitable spray equipment using the following rates: asphalt emulsion 0.04 gallons per square yd; liquid asphalt (rapid, medium, or slow setting) 0.10 gallons per sq. yd. |
| 2. Wood cellulose fiber | Hay or straw | Apply with hydroseeder immediately after mulching. Use 750 lbs. wood fiber per acre. |
| 3. Pick Chain | Hay or straw, manure compost, pine straw | Use on slopes steeper than 3:1. Pull across slopes with suitable power equipment. |
| 4. Mulch Anchoring Tool or disk (smooth or notched) | Hay or straw, manure pine straw | Apply mulch and pull a mulch anchoring tool over mulch. When a disk (smooth) is used, set in straight position and pull across slope with suitable power equipment. Mulch material should be tucked into soil surface about 3". |
| 5. Chemical | Hay or straw | Apply Terra Tack 11 (45 lbs.) or Aerospray 70 (60 gal./A.) according to manufacturer's instructions. Avoid application during rain. A 24 hour curing period required and soil temperature higher than 45°F. |

39

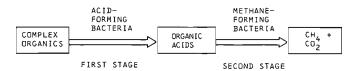# Gas Venting Systems:
# Methane Recovery and Migration Control

DR. WILLIAM GRANER

Charles Velzy Assoc., Babylon, New York

## ABSTRACT

*The process of anaerobic decomposition of organic matter in sanitary landfills proceeds in two successive stages: 1) generation of organic acids by acidifying bacteria and 2) formation of methane and carbon dioxide by methanogenic bacteria. The rate of decomposition is contingent on the composition of the refuse—foodstuffs generally complete decomposition in 1/2-1 1/2 years; paper, textiles and wood may require 30 years for decomposition; plastics and rubber decompose after 30 years; some materials never decompose. The evolution of typical landfill gas composition occurs in four stages: 1) aerobic (inhibits methanogenesis); 2) anaerobic-non-methanogenic; 3) anaerobic-methanogenic, unsteady production rate; and 4) anaerobic-methanogenic, steady production rate. Moisture content, temperature and pH influence gas generation. Air infiltration is the most critical factor of the landfill stabilization process. Landfill depths of 30-40 feet are suitable as recovery sites if air infiltration is minimized; depths greater than 100 feet are preferable. Sealing and capping are measures to prevent air infiltration and leakage around well casings. To extract methane, perforated casings are implanted into the landfill and connected to extraction fans that regulate flow rate. A pumping rate should be achieved that yields a stable methane content above 45% and an oxygen content below 4%. Monitoring probes should be installed to record gas pressure data to optimize well spacing for recovery. A potentially hazardous condition exists when oxygen levels increase to about 14% and greater; therefore, active wells must be monitored regularly. Buildings and property adjacent to landfills are protected by installing methane migration control systems that may include wells, trenches, vents or combinations of each.*

## INTRODUCTION

It has been recognized for many years that sanitary landfills containing decomposable material produce gas. However, scientific investigations to quantify this process are only a few years old. The stages of anaerobic decomposition of complex organic wastes and other materials deposited in a sanitary landfill are summarized in Figure 19. This anaerobic decomposition is generally considered to proceed through two basic stages: *1. is the generation of organic acids by acid-forming bacteria, and 2. is the formation of methane and carbon dioxide by methane-forming bacteria.* The system is a dynamic process because decomposition occurs at different rates, owing to the variable composition of municipal refuse. For example, rapidly decomposing materials such as food stuffs and other organic type wastes generally decompose in about 1/2 to 1 1/2 years. Moderately decomposable materials, such as paper, textiles and wood, may require anywhere from five to thirty years for decomposition to occur. Refractory materials like plastics and rubber have even longer time periods, while some materials will not decompose at all.
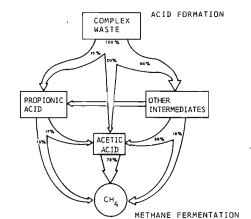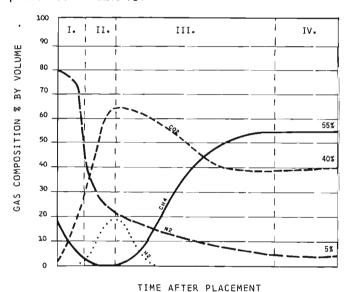


Figure 19  *Anaerobic decomposition of complex organic waste*

41

The evolution of typical quality landfill gas is considered to occur in four time stages after placement of refuse into the landfill (Figure 20). In the first stage the fill is aerobic since refuse as delivered is relatively high in oxygen content. The oxygen is toxic to anaerobic organisms and inhibits formation of methane bacteria. Consequently, there is a period of time (several weeks to months) before the system becomes anaerobic. During the second and third stages, acid and methane-forming bacteria develop, causing increases in carbon dioxide and methane. These end products are characteristic of the anaerobic process. The gas composition, expressed as percent by volume, levels off during the fourth and final stages of anaerobic decomposition. Although the system represented in Figure 20 appears straightforward, it is extremely complex, because of the numerous variables inherent in the process. Refuse characteristics, placement conditions, weather conditions and related factors result in methane generation extending over a period of two to thirty years or more, and are reflective of a landfill being a dynamic system.

Other conditions, which are variables relative to gas production, include moisture content, temperature, alkalinity and pH to mention a few. Stoichiometrically, the maximum methane production from refuse is approximately four cubic feet of methane per pound of refuse. In practicality, however, the methane production rate may be substantially less depending upon the refuse characteristics and the environment of the landfill itself. Typically, gas composition at system equilibrium is considered to be about 55% by volume methane and 40% by volume carbon dioxide. However, actual measured gas concentrations have been found to vary significantly, depending upon specific site limitations and conditions. Ranges in gas composition for various constituents are presented in Table 13.



TIME AFTER PLACEMENT

I. AEROBIC

II. ANAEROBIC, NON-METHANOGENIC

III. ANAEROBIC, METHANOGENIC, UNSTEADY

IV. ANAEROBIC, METHANOGENIC, STEADY

Figure 20  *Evolution of typical landfill gas composition*

Optimal conditions for anaerobic decomposition are also shown in Table 13. It is suggested that the moisture content should be greater than 40%, and experience indicates that a moisture content of about 60% is preferred. It should be noted that refuse as received into a landfill generally has a moisture content in the range of 25%. Therefore, to optimize the decomposition process an increase in moisture content is necessary. This added moisture can come from several sources. Water is generated by the decomposition process itself, it comes in the form of natural precipitation and, in some instances, from the recycling of landfill leachate. It has been reported by some investigators that increased methane generation is observed following periods of heavy precipitation. Others claim that changing barometric pressure alone will affect methane production. One thing is certain. **Methane levels vary with weather conditions, and with moisture content within the landfill.**

*METHANE RECOVERY*

Although in many respects methane recovery and methane migration control are similar from an engineering standpoint, they are viewed as having different objectives. To develop a gas recovery system the following system objectives are required:
- *To determine optimum gas withdrawal rates*
- *To determine gas quality at various withdrawal rates*
- *To determine the optimum well spacing*
- *To determine the effect of additional moisture in gas production.*
- *To evaluate the applicability of various modes of gas utilization*

The installation of recovery wells has been a changing technology as more systems become operational and testing programs are completed. Examples of typical venting well configurations that have been used in the industry are shown in Figure 21. Until recently, venting wells were constructed by installing a bore hole of about 36 inch diameter with a 6 or 8 inch diameter perforated pipe within a gravel pack. This technology is based upon techniques used in the water supply industry. The recovery of gas is different from drawing water from an aquifer and the need for a gravel-packed well installation is being questioned. Most recent installations have been without gravel packs and have resulted in substantially lower construction costs. Within fill areas, wells are also being designed as conventional piles, and are being installed using pile-driving procedures. Well-drilling by this method is accomplished at reduced costs and in a fraction of the time needed for conventional installation techniques.

The factor which is probably most critical to the landfill stabilization process, particularly when methane recovery is the objective, is **air infiltration**. Air has been found to move readily in and out of the surface of the landfill as barometric pressure increases and decreases. This was generally unexpected since it was assumed that a few feet of compacted clay would severely reduce air infiltration. Air leakage through the gravel pack of recovery wells has also been a problem at several installations.

# TABLE 13
## Measured Gas Composition

| CONSTITUENT | VOLUME % | | |
| --- | --- | --- | --- |
| | Avg. | High | Low |
| Methane | 44.03 | 46.49 | 41.38 |
| Carbon Dioxide | 34.20 | 36.80 | 30.73 |
| Nitrogen | 20.81 | 23.51 | 19.98 |
| Oxygen and Argon≠ | 0.96 | 1.69 | 0.48 |
| Water | Saturated at 14.7 psia and 90°F | | |
| | grains per 100 ft. 3* | | |
| Hydrogen Sulfide | 0.40 - 0.91 | | |
| Mercaptan Sulfur | 0.00 - 0.33 | | |
| Sulfides | 0.41 - 1.80 | | |
| Disulfides and Residuals | 0.93 - 1.65 | | |

≠ Ar represents at least 50% of the total

* To convert to ppm multiply by 17, 7.63, 6.44 and 4.75 for $H_2S$, mercaptan, sulfides and disulfides, respectively

## Optimal Conditions for Anerobic Decomposition

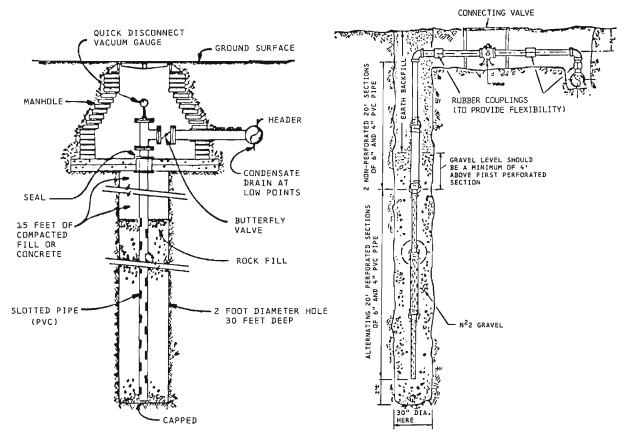| | |
| --- | --- |
| Anaerobic Conditions | No Oxygen (Air) |
| Temperature | 85-100°F (29-37°C) |
| pH | 6.8-7.2 |
| Moisture Content | Greater Than 40 Percent |
| Toxic Materials | None |



Figure 21  *Typical venting well configurations*

Fill areas greater than 100 feet in depth are considered ideal for gas recovery systems. It has been reported that depths of 30-40 feet are suitable as recovery sites providing more control over minimizing air infiltration is achieved. Depths less than 30 feet are considered as poor because the gas withdrawal rates must be kept uneconomically low, so that air infiltration will not inhibit methane production.

Optimum depths of gas recovery wells can only be based upon adequate field testing and sampling. It has been found that wells need not penetrate the entire fill depth to capture gases from the system. One important aspect is that adequate sealing and capping of the well be accomplished to avoid air infiltration and leakage around the well casing. It is suggested that the perforated casing should end more than 10 feet below grade surface and this upper layer backfilled with clay or other impervious material. This technique will minimize air leakage and infiltration into the system.

A preliminary estimate of the gas production potential of a well can be made by measuring:

- *Its static pressure*
- *Its blow-off rate*
- *Gas temperature*
- *Methane content of the blow-off*

It has been found that gas pressure can build up in a landfill as high as 3 inches of water column static pressure. Gas sampling in recently uncapped or capped casings can be misleading, and methane readings should be taken no sooner than, at least 30 minutes after free blow-off. In order to properly evaluate a well for its best long-term methane production rate, it should be pumped continuously for at least a one month period. A promising production well should exhibit the following characteristics:

- *Pressure of 2.5 inches of water column*
- *Blow-off rate of 80 CFM (from a 6 inch casing)*
- *Gas temperature of about 115°F*
- *Combustible gas content of about 55 percent*

The methodology for a gas venting well production test consists of drawing on a well with a mechanical fan at some initial flow rate. It has been suggested that this initial rate be no more than 3-4 times the blow-off rate. The methane and oxygen content should be closely monitored, i.e., by daily sampling. The fan used should be capable of having its own flow adjustment (speed changer, changing sheaves on V Belt drive, throttling valves, etc.). If the observed methane drops below 45% and/or oxygen increases markedly, pumping should be stopped for about two days and then testing resumed at a significantly lower flow rate. The testing procedures should again be followed at each lower flow rate. By several trials, a pumping rate should be found that yields a stable methane content above 45% and oxygen content less than 4%, but preferably less than 1%.

To evaluate the radius of influence to optimize well spacing for recovery and/or migration control wells, and to produce gas pressure data, it is necessary to install monitoring probes. A typical landfill gas recovery well and probes are shown in Figure 22. These satellite probes are installed at selected distances, e.g., 50', 100', 150', etc. from the test well. **Static pressures** are generally taken with a manometer from the test and observation probe wells. During the testing program the static pressure should be measured at each probe when the gas content is measured at the pumping well.
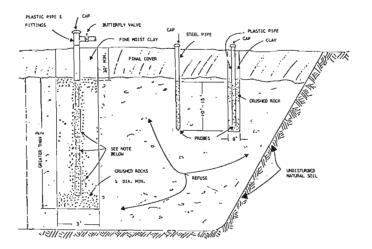


**Figure 22** *Typical landfill gas recovery well and probes*

The effect of short-term pumping on methane gas concentration, and the pressure changes due to different withdrawal rates, can be observed in Figures 23 through 26. These results are from an Environmental Protection Agency (EPA) demonstration project conducted at Mountain View, California. This landfill had a depth of approximately 40 feet. The withdrawal wells were provided with perforations at two depths. One was situated in the bottom of the landfill (32 to 40 feet below grade) while the second was just below mid-depth (20 to 28 feet below grade surface). Figures 23 and 24 present contours of methane gas distribution prior to and after short-term pumping from Well B situated at mid-depth within the landfill. The contours of gas distribution for this test were substantially altered and the methane content by percent volume drastically reduced in upper areas of the fill.

Comparisons of the pressure distribution for different withdrawal rates when pumping from the bottom and mid-depth of the fill are shown in Figures 25 and 26 respectively. It was also observed at this demonstration site that air infiltration was a problem at high withdrawal rates due to the shallow landfill depth, particularly when sampling from Well B at mid-depth. They also found changes in gas production as a result of changing barometric pressure.

It must be noted that an explosive mixture exists whenever a landfill gas mixture has more than 5% methane and more than about 14% oxygen. The gas in a recovery well is usually within a safe oxygen range (below 4%). However, if and when air mixes with landfill gas, hazardous conditions could exist. Therefore, active wells must be regularly checked for their oxygen and methane content. Subsidence cracks and protracted dry weather conditions sometimes cause these wells to yield ex-

CENTERLINE OF WITHDRAWAL WELL
TOP OF LANDFILL

BOTTOM OF LANDFILL

DISTANCE FROM WELL (FT)= R

DISTRIBUTION OF GAS

METHANE GAS

CONTOURS SHOW CONCENTRATION OF METHANE GAS PRIOR
TO SHORT-TERM PUMPING.
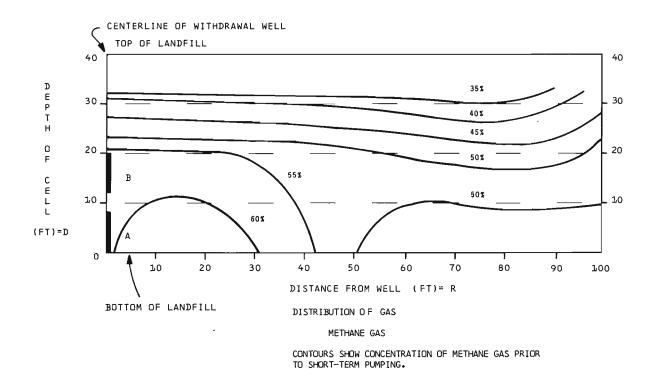
**Figure 23**  *Distribution of methane gas prior to short term pumping*



CENTERLINE OF WITHDRAWAL WELL
TOP OF LANDFILL

BOTTOM OF LANDFILL

DISTANCE FORM WELL (FT)=R

DISTRIBUTION OF GAS

METHANE GAS

CONTOURS SHOW CONCENTRATION OF METHANE GAS
AFTER THE SHORT-TERM PUMPING.
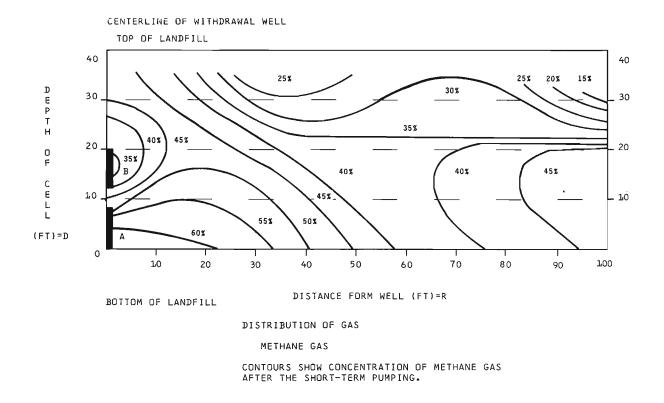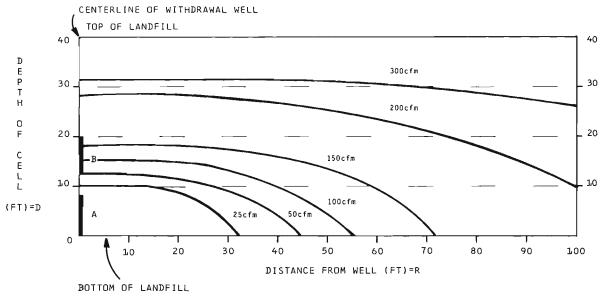
**Figure 24**  *Distribution of methane gas after short term pumping*

CENTERLINE OF WITHDRAWAL WELL

TOP OF LANDFILL

DISTANCE FROM WELL (FT)=R

BOTTOM OF LANDFILL

PRESSURE DIAGRAM

FOR ONE-INCH WATER PRESSURE CONTOUR AT
DIFFERENT WITHDRAWAL RATES WHEN LANDFILL
GAS IS WITHDRAWN AT POINT A

Figure 25 *Pressure diagram when landfill gas is withdrawn at "A"*



CENTERLINE OF WITHDRAWAL WELL

TOP OF CELL

DISTANCE FROM WELL (FT) = R

BOTTOM OF CELL

PRESSURE DIAGRAM

FOR ONE-INCH WATER PRESSURE CONTOUR AT DIFFERENT
WITHDRAWAL RATES WHEN LANDFILL GAS IS WITHDRAWN
AT POINT B

Figure 26 *Pressure diagram when landfill gas is withdrawn at "B"*

46

plosive mixtures. Thus, a continual maintenance program of the fill surface must be instituted to prevent the accidental introduction of large quantities of air into the gas recovery systems.

### METHANE MIGRATION CONTROL

Because of the explosive potential of the landfill gas mixture, it is essential that buildings and property adjacent to landfills be protected. This is accomplished by installing **methane migration control systems,** which may include natural venting or forced ventilation systems. These systems may include wells, trenches, vents or combinations of each.
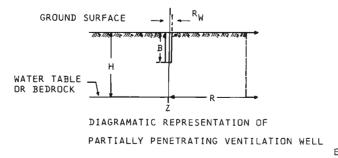
The objective of a testing program for methane migration control systems is to obtain an approximation of the minimum gas withdrawal rate and well spacing required to prevent or minimize gas migration beyond the limits of the landfill site. Testing procedures are similar to those for methane recovery. After installation of satellite probes at selected distances the static pressures are taken at the venting well and probes. The venting well is pumped at a constant vacuum for several days. Daily gas and static pressure readings are then taken at the probes. Each test run should be followed by a closure period of several days to allow gas to migrate back into
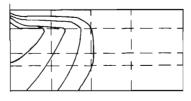
the test probe area. The vacuum is changed on the gas well and the procedure repeated. For each test run, pressure contours or equipotential lines are plotted for each withdrawal rate, to establish the required well spacing and the minimum gas withdrawal rate.

Test results of a typical methane migration study are shown in Figures 27 through 29. In this program, five wells were connected to a common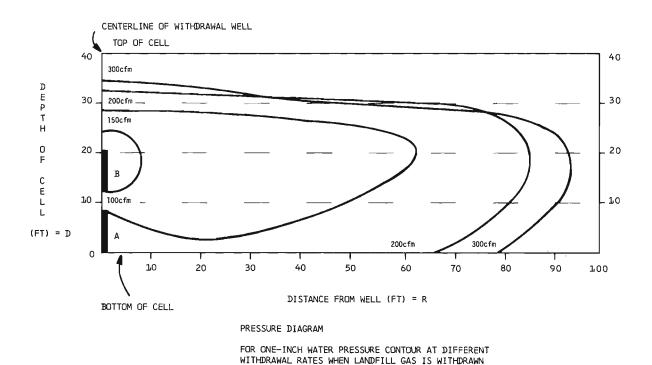 blower, and negative pressures were measured in probe wells off the landfill site. Tests were performed at withdrawal rates of 200, 315 and 630 cfm. Equipotential lines of negative pressure, in inches of water, for each withdrawal rate is shown in Figure 27.
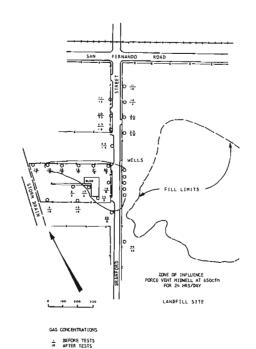
To achieve a zero methane concentration at a building site adjacent to the landfill, it was necessary to pump at rates exceeding 315 cfm. The zone of influence (zero methane concentration) and methane levels before and after tests at 650 and 315 cfm are presented in Figures 28 and 29 respectively.
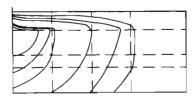
Adequate testing has proven to be essential for establishing an effective methane migration system. In too many instances, venting wells have been installed as a reaction to a civic association and regulatory agency pressures, without regard to the testing and evaluations necessary to properly engineer these systems.



DIAGRAMATIC REPRESENTATION OF
PARTIALLY PENETRATING VENTILATION WELL



ESTIMATED EQUIPOTENTIAL LINES FOR Q = 200cfm (0.00 m³/s)



ESTIMATED EQUIPOTENTIAL LINES FOR Q = 315cfm (0.15 m³/s)



ESTIMATED EQUIPOTENTIAL LINES FOR Q = 630cfm (0.29 m³/s)



Figure 27  *Typical methane migration study*

47

**Figure 28** *Typical methane migration study @ 650 cfm*



**Figure 29** *Typical methane migration study @ 315 cfm*

# Landfill Gas Recovery in New York State

ELLEN BOGARDUS
New York State Energy Office, Albany, New York

*ABSTRACT*

*The recovery and use of methane from landfills has been a growing practice in the United States since the mid 1970's. In New York State, a research project initiated in 1977 at the Fresh Kills landfill was designed to determine optimum gas withdrawal rates, spacing of wells, reliability of landfill gas as a fuel for a prime mover, and the corrosive effects of landfill gas on the components of a gas utilization system. Getty Synthetic Fuels, Inc. anticipates operating the first commercial New York State recovery facility by the summer of 1982, at which time they will be extracting 8.4 million cubic feet of landfill gas per day from a 400-acre tract of the Fresh Kills landfill; gas needs for 15,000 Staten Island residences will be met by this project. The objectives of the New York State Energy Office landfill gas program include assessing the resource potential of landfill gas in New York State, and promoting landfill gas development at state sites with significant recovery potential. Thirty-nine of the more than 600 state landfills meet the initial criteria for inclusion in this resource assessment. Studies indicate that there is considerable potential for commercial recovery of energy from a number of New York State's larger landfills. Various economic, technical and regulatory issues tend to retard the rapid implementation of landfill gas projects in New York State: economic uncertainties include marketing difficulties and high perception of risk; technical uncertainties include landfill gas generation rates, condensate handling, air intrusion control and air quality considerations; and regulatory uncertainties exist on the Federal, State and local levels. Recovery systems may be operated in conjunction with a control system, especially if perimeter migration control or odor control is necessary. Three primary applications for landfill methane are medium-BTU gas for industrial use, medium-BTU gas for electricity generation and conversion to high-BTU pipeline standard gas for injection into utility company pipelines. The end use of the landfill gas will, to a large extent, determine the complexity of the recovery system. The mini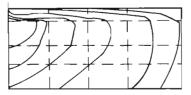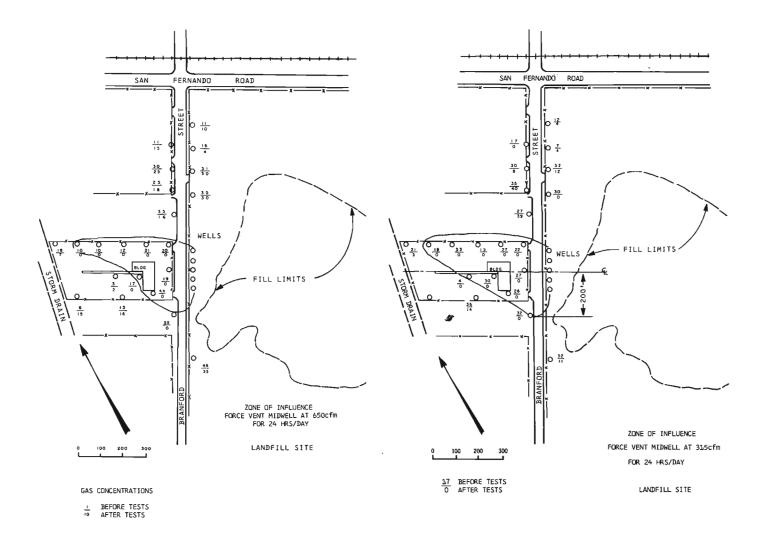mum requirements for gas recovery include:* 1) an in-place solid waste tonnage of two million tons, 2) a solid waste disposal rate of 150 tons per day, 3) an average refuse depth of 40 feet, 4) a surface area of 40 acres, and 5) two years of remaining active fill life. *The Energy Office projects that, by 1994, approximately 3 percent of New York State's natural gas needs could be met by gas recovered from landfills.*

A number of you in the audience are quite familiar with the program that I have been running for the Energy Office for about a year-and-a-half on landfill gas recovery, but for those of you who are not, I'm going to refer to two recent publications of the Energy Office. One is *Landfill Gas: An Analysis of Options.* The other one is the report *The Analysis of Methane Potential at New York State Sanitary Landfill Sites.*

The recovery and use of methane from landfills has been a growing practice in the United States since the mid 1970's. Nine major gas recovery projects are in existence today, with a score of others in an advanced state of development. While there have been improvements in gas gathering techniques, in well design and in processing methods, which have resulted in a high degree of technical reliability, projects have, to date, been concentrated in California, and thus the technology is less familiar in the East.

So, this afternoon, what I want to do is review the current New York State gas recovery projects, review the landfill gas program that the Energy Office has had going on for a year-and-a-half, and then highlight some of the factors that should be considered in determining the feasibility of a landfill gas recovery system.

An important catalyst in generating initial interest in landfill gas technology in New York State has been the research project initiated in 1977 at a forty-acre plot at the Fresh Kills landfill on Staten Island, New York. This project was co-funded by the New York State Energy Research and Development Authority, the New York City Office of Resource Recovery and Waste Disposal Planning, the Brooklyn Union Gas Company and the United States Department of Energy. There is a lot of garbage at the Fresh Kills site. An average of 2,000 tons per day are

unloaded there.

The purpose of the project was to determine the following:

- *optimum gas withdrawal rates,*
- *well spacing,*
- *the reliability of landfill gas as a fuel for a prime mover,*
- *the corrosive effects of landfill gas upon the components of a gas utilization system.*

This project has just recently come to a conclusion. Getty Synthetic Fuels, Inc. anticipate starting up the first commercial New York State recovery facility by the summer of 1982, at which time they will be extracting 8.4 million cubic feet of landfill gas per day from a 400-acre tract of the Fresh Kills landfill. This gas will be upgraded to pipeline quality for sale to the Brooklyn Union Gas Company's distribution network. Gas needs for 15,000 residences on Staten Island will be met by this recovered gas.
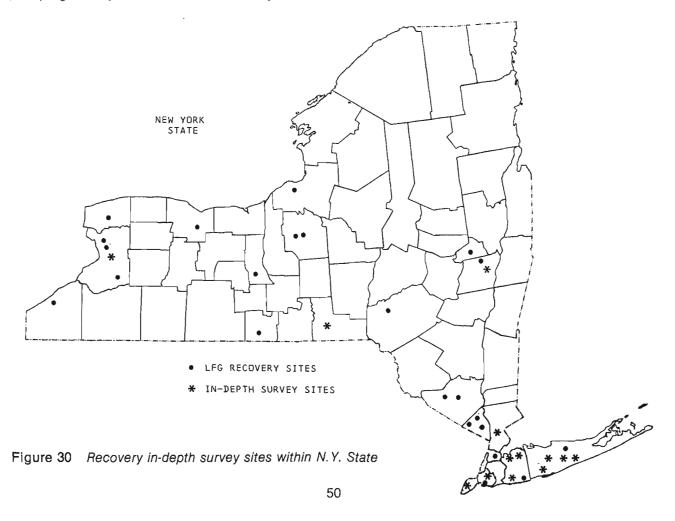
A second commercial recovery project will be developed by Wehran Energy Corporation at New York City's Pelham Bay landfill in the Bronx. Testing has commenced, and the expected use for the gas will be as a medium BTU boiler fuel at Co-op City. They expect a start-up date for that project as early as 1983.

The New York State Energy Office landfill gas program was initiated in March of 1980. To encourage the systematic development of landfill gas recovery Statewide, the program objectives included assessing the re-source potential of landfill gas in New York State, and promoting landfill gas development at state sites with significant recovery potential. State legislation, passed in June 1980, directed the Energy Office to survey and report to the legislature on the methane production potential from the state's landfills. In order to fulfill this legislative mandate, a request for proposals to prepare the resource assessment was issued, with the contract be-ing awarded to GENSTAR/Gas Recovery Systems of Pasadena, California in August 1980.

Thirty-nine of the more than 600 state landfills met the initial criteria for inclusion in this resource assessment, and Figure 30 shows where those thirty-nine sites were located throughout the State. Sixteen prime commercial gas recovery sites were then selected for in-depth analysis, and those are the starred ones.

Tasks involved in this part of the study included eighteen site visits and discussions with public works officials, potential gas users and utilities. The final two hundred-page report, *Analysis of Methane Potential at New York State Sanitary Landfill Sites,* was issued in June 1981. This report presents general information about New York State landfills, utilization alternatives for the recovered methane, and general process explanations. The site specific studies for the sixteen prime commercial prospects include background information on the sites, including potential markets for the gas; gas production prediction curves; capital and operating costs for primary utilization modes, and suggested business alternatives.



NEW YORK
STATE

• LFG RECOVERY SITES

* IN—DEPTH SURVEY SITES

Figure 30 *Recovery in-depth survey sites within N.Y. State*

50

The findings of this study indicate that there is considerable potential for commercial recovery of energy from a number of New York State's larger landfills. Active tonnage in place at the sixteen primary sites is equal to more than 110 million tons. The methane available is projected to be roughly seven billion cubic feet a year, with an annual worth of $29,000,000 based on $4.00 per million BTU's.

On a site specific basis, there are factors which favor and other factors which discourage development of landfills in New York State. One of the factors favoring development is that there is considerable water infiltration into the landfills as a result of high rainfall levels. This accelerates the decomposition of the refuse and leads to high annual gas production rates per unit weight of refuse.

The energy market in New York State has been heavily impacted, both by gas supply interruptions in the past and by the State's excessive dependence on an insecure and high-priced source of imported petroleum. While no one favors high energy prices, the fact that they exist in New York favors development of new supplemental sources of energy, such as landfill gas.

On the negative side, many New York State landfills are relatively small, making it difficult to obtain acceptable and cost effective methane recovery rates. This is not, however, the case in New York City or on Long Island, where some excellent prospects exist.

The primary constraints related to developing New York City landfills appear to be regulatory in nature, while many of the Long Island sites have sandy base soils and cover materials, which make it difficult to contain the extracted gas without drawing in a certain amount of air. This can poison the methane-producing microorganisms and contaminate the process gas stream. It is very important that this issue be properly addressed, since it is one of the major factors affecting the utilization alternatives, which can be considered for any given Long Island landfill.

A key responsibility of the Energy Office's Bureau of Resource Development in technology promotion is the identification and removal of barriers restricting commercial project implementation. Various economics, technical and regulatory issues tend to retard the rapid implementation of landfill gas projects in New York State. Economic uncertainties include marketing difficulties and a high perception of risk. Technical uncertainties include landfill gas generation rates, condensate handling, air intrusion control and air quality considerations. To increase awareness of the technology, the Energy Office sponsored a day-long landfill gas seminar on Long Island in May 1981, in conjunction with the New York State Solid Waste Management Association's spring meeting. Close to 150 persons attended this in-depth east coast meeting on landfill gas recovery, which featured key speakers from California addressing the development of this alternate energy resource. A booklet, *Landfill Gas: An Analysis of Options,* was prepared for the meeting and is available for general distribution from the Energy Office.

Regulatory constraints on proposed landfill gas projects are numerous and complex. Regulatory uncertainties exist on the Federal, State and local level. Hopefully, as the public, municipal and state decision makers and legislators become better informed of the environmental and economic benefits of landfill gas recovery, these regulatory constraints will lessen. Several actions have been initiated by bureau staff relative to reducing various regulatory constraints to landfill gas development.

A bill was introduced and passed during the 1981 legislative session to exempt alternate energy production facilities producing gas from Public Service Commission jurisdiction, except for certain matters of safety. That bill was signed by the Governor in August of this year.

Bureau staff coordinated a meeting with top policy decision makers in the Division of Air Resources and the Division of Solid Waste at the New York State Department of Environmental Conservation to discuss basic issues regarding condensate return and air emissions from the proposed Getty Synthetic Fuels landfill gas processing plant at the Fresh Kills landfill. An ad hoc committee is being formed to formulate State policies on these matters.

Now, some factors to consider in a typical landfill gas recovery project:

The typical gas recovery system in use today employs induced exhaust wells, consisting of perforated pipe casing placed in holes drilled in the refuse, backfilled with permeable material and sealed with impermeable material to prevent the inflow of air, as shown in Figure 31. Suction is applied to each well casing to withdraw the gas and transport it to a processing area by means of a pipe network, referred to as a gas collection header. A motor or engine-driven compressor is usually the source of the applied suction, as well as the central point for collection of the gas. Each well head is normally connected to the gas collection header by means of flexible hose and a flow control valve, which allows for thermal expansion and contraction, differential settlement and flow adjustment. At the process facility, the gas is treated to remove particulate matter, moisture, carbon dioxide, and, often, trace gases. The pressure of the gas may be increased and the temperature lowered, if required for transmission. Sales and use requirements determine the extent to which the gas is processed.

Recovery systems may be operated in conjunction with a control system, particularly if perimeter migration control or control of odors is necessary. Sometimes already existing control wells can be modified to operate as recovery wells; however, there is basic incompatibility between wells designed for control and those designed for recovery, since control wells often admit large quantities of air which are toxic to methane-producing bacteria. Not only does this reduce potential recovery rates, but it also contributes to a gas of lower quality, requiring costly upgrading to achieve acceptable BTU values. If a control system and a recovery system are to operate simultaneously, each system will usually have its own collection header.

High quality gas from the specially designed or modified recovery wells will be transmitted to the processing facility, and from these to the end-user. Air-rich gas from the control system may be collected and flared or put to such on-site uses as fueling the gas-engine of the compressor.
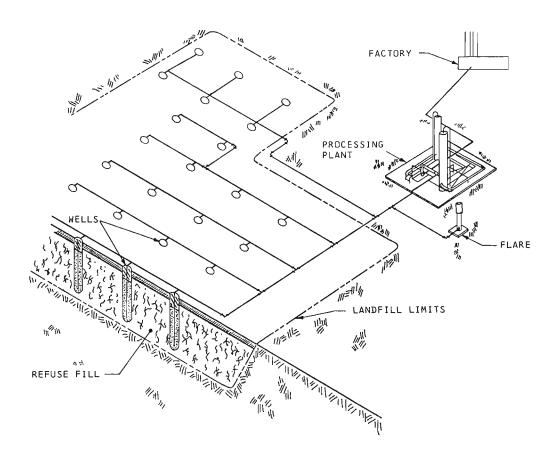
Figure 31 *Gas recovery system*

Of the existing recovery projects, at least three (Palos Verdes, Operating Industries, and Sheldon-Arleta) have a competing perimeter control system which is independent of the gas recovery system. This system is required in order to control off-site gas migration. At Azuza Western and Bradley landfills, on the other hand, the gas recovery system alone provides effective migration control.

There are three primary categories of use for methane from landfills:

- *The direct sale of partially cleaned up medium-BTU gas (500-600 BTU/SCF) to industrial customers.*
- *Utilization of medium-BTU gas as a source of fuel for electricity generation.*
- *Conversion of landfill gas to pipeline standard gas (1000 BTU/SCF) for injection into nearby utility company pipelines.*

Upgraded gas can also be used to fuel conventional vehicles with converted carburetion systems. Methane as an alternate vehicle fuel is receiving ever-increasing attention in New York State.

The end use of the landfill gas will, to a large extent, determine the complexity of the recovery system. If landfill gas is to be used as a medium-BTU gas, the only processing required is simple water and particulate removal. There is no need for an elaborate and expensive processing technology. Furthermore, since such uses do not require large volumes of gas, they are suited to the smaller landfills.

For pipeline quality gas, in addition to moisture and particulate removal, processing will include $CO_2$ removal. The process technology necessary to achieve this quality gas is relatively straightforward, off-the-shelf technology, but large capital expenditures are involved.

Marketing is vital to the economic feasibility of landfill gas recovery projects. Until the gas is actually sold, it has no economic value as a resource. For this reason, available markets should be considered before decisions are made relative to project technology.

Not all landfills produce enough gas or gas of sufficient heating value to be likely candidates for a major recovery project. Due to the high capital cost of recovery projects, generally in excess of $1,000,000, only a fraction of existing landfills presently qualify as economical large-scale recovery projects. The following are considered to be minimum requirements for recovery:

- *an in-place tonnage of two million tons*
- *a disposal rate of 150 tons per day*
- *an average refuse depth of forty feet*
- *a surface area of forty acres*
- *two years of remaining active fill life.*

It is probable that fewer than 200 landfills in the United States are of sufficient size to meet these criteria. However, as the price of natural gas increases, as nearby landfills explore the possibilities of combined gas recovery projects, and as methods of enhancing gas pro-

duction and collection are developed, it is likely that many more landfills will find it economically feasible to consider modest recovery programs. Most landfill gas development to date has occurred in California. Table 14 is a list of 8 California projects and one New Jersey, giving some essential statistics for each.

The Energy Office program in landfill gas will gradually be reduced as development by the private sector increases and risk perceptions diminish. Since the resource assessment of the methane potential of New York State landfills has been completed, the Energy Of-

fice's future efforts in the landfill gas program will be to concentrate on identifying and modifying those legal and institutional barriers hindering landfill gas projects in the state.

Projections by the Energy Office show that, by 1994, roughly 3 percent of New York State's natural gas needs could be met by gas recovered from landfills. Given that the State's indigenous natural gas production in 1980 equaled only 2.6 percent of its total gas requirement, landfill gas unquestionably represents a considerable untapped energy resource for New York State.

## TABLE 14
### Existing Gas Recovery Facilities

| Project | Owner/Operator | Process Description and Project Status |
|---|---|---|
| Ascon - Wilmington, CA | Watson Energy Systems | Condensate and particulate removal; 1.5 million cfd medium-Btu gas to Shell Oil refinery for steam generation. In operation since late 1978. |
| Azusa Western - Azusa, CA | Azusa Land Reclamation | Dehydration and acid removal; 500,000 cfd delivered to chemical company to generate steam. In operation since early 1978. Current plans to generate electricity for City of Azusa. |
| Bradley - Sun Valley, CA | Gas Recovery Systems, Inc. | Dehydration and particulate removal; 2.5 million cfd medium-Btu gas for steam generation at Valley Steam Plant. Commercial operation since January 1981. |
| Cinnaminson - Newark, NJ | Public Service Electric & Gas | Sulfur and condensate removal; 250,000 cfd medium-Btu gas to power steel plant for heating. In operation since Fall 1979. |
| City of Industry - City of Industry, CA | City of Industry | Dehydration and particulate removal; 500,000 cfd medium-Btu gas for heating and cooling convention center facilities. In the start-up phase. |
| Monterey Park - Monterey Park, CA | Getty Synthetic Fuels, Inc. | Dehydration and carbon dioxide removal; 4 million cfd pipeline quality gas to Southern California Gas Company. Operational since August 1979. |
| Mountain View - Mountain View, CA | Pacific Gas & Electric Co. | Dehydration and carbon dioxide removal; 750,000 cfd high-Btu gas for blending into pipeline. Operated as experimental facility since 1979; currently involved in 1-year commercial project to evaluate feasibility. |
| Palos Verdes - Rolling Hills Estates, CA | Getty Synthetic Fuels, Inc. | Dehydration and carbon dioxide gas removal; 750,000 cfd pipeline quality gas to Southern California Gas Company. In operation since June 1975. |
| Sheldon-Arleta - Los Angeles, CA | City of Los Angeles | Dehydration and particulate removal; 2.6 million cfd medium-Btu gas for steam generation at nearby plant. Commercial operation since November 1979. |

# 6 NYCRR Part 360 Rules and Regulations, and Assistance

DENNIS J. WOLTERDING

New York State Department of Environmental Conservation, Albany, N.Y.

*ABSTRACT*

*The Bureau of Municipal Waste is responsible for the Part 360 permitting of nonhazardous solid waste management facilities including incinerators, landfills, transfer stations, landspreading facilities and resource recovery plants. The intent of 6 NYCRR Part 360 is to ensure that a solid waste management activity permitted by the State Department of Environmental Conservation (DEC), will have no significant adverse impacts on public health, safety or welfare. A sanitary landfill is defined as a facility which complies with 40 CFR Part 257 and is presumed to pose no significant probability of adverse effect. New York State had to revise its regulations to coincide with Federal requirements to end open dumping and upgrade or close open dumps. For mixed municipal waste landfills, financial guarantees for monitoring and maintenance are ordinarily required for five years after closure. Part 360.8 (b) (1) (i) specifies that a vertical separation exceeding five feet shall be maintained between solid waste and both bedrock and the seasonal high groundwater table. Paragraph 360.8 (b) (1) (xvii) states that all new sanitary landfills and modifications of existing facilities must be lined by a material that restricts infiltration to that achieved by five feet of soil with a coefficient of permeability of $10^{-5}$cm/sec. the facilities must also have leachate collection and storage capabilities. Part 360.8 (a) (1) dictates that refuse shall not be directly deposited in water, and 360.8 (a) (3) makes it a violation for leachate to be discharged into a surface water in the absence of a State Polutant Discharge Elimination System permit. A number of criteria in Part 360 deal directly or indirectly with groundwater contamination. Minimum DEC groundwater monitoring requirements are presented in 360.8 (b) (1) (iii), which requires that a network of at least three wells, one hydraulically upgradient of the landfill, the other two hydraulically downgradient of it, must be emplaced at a solid waste disposal facility. Certain chemical constitutents of leachate such as chloride, iron and total dissolved solids are indices of landfill pollution and can be used to profile the saturated zone near a disposal site. Sampling techniques and frequencies for screening for contamination are outlined in 360.8 (b) (1) (iv) and 360.8 (b) (1) (v). Other paragraphs present regulations for precluding deployment of future landfills in dangerous proximity to airports, for specifying that the decomposition gases shall not pose a hazard to public health, safety or property, and for capping requirments. The outlook on Federal funding to upgrade or close open dumps is not bright.*

THE BUREAU OF MUNICIPAL WASTE, an arm of the Division of Solid Waste of the New York State Department of Environmental Conservation (DEC) in Albany, New York, is responsible for the Part 360 permitting of nonhazardous solid waste management facilities. These include incinerators, landfills, transfer stations, landspreading facilities, resource recovery plants, and others as defined in *Article 27, Title 7 of the Environmental Conservation Law.*

In addition to being the staff geologist, I have also been co-administrator of a statewide investigation of landfills termed the **Open Dump Inventory,** an initiative called for under *Section 4005 of the Federal Resource Conservation and Recovery Act of 1976 (P.L. 94-580, also know as RCRA).*

Lastly, by way of background, I served on the *Part 360 Revisions Task Force* which first met in the Fall of 1979 and which culminated in promulgation of the revised regulation that went into effect on May 5th, 1981. It will be this particular regulation I'll be talking about today, and only about presumably non-hazardous waste facilities—that is municipal landfills.

Let's begin with the intent of *6 NYCRR Part 360,* an intent parallel to that of *Subtitle D of RCRA.* Foremost, the regulation (as stated in 360.1[a] and 360.4[a]) seeks to protect the people of the State. It also attempts to ensure that a DEC-permitted solid waste management activity will have no significant adverse impact on public health, safety or welfare. If the language sounds familiar, it is because it derives almost verbatim from Section 1003

of RCRA, which calls for an end to open dumping on land and the conversion of existing facilities into ones which do not pose a threat to public health and environment.

Figure 32 shows the *RCRA Criteria, 40 CFR Part 257,* that were promulgated by the United States Environmental Protection Agency (USEPA) on September 13, 1979 to realize Federal objectives with regard to solid waste disposal facilities and practices. These Criteria define in regulation something called an **open dump.** Although we're all familiar with the town dump of old, where rats and refrigerators could often be found juxtaposed in an uncovered pit, an open dump by Federal definition is any solid waste disposal facility (not otherwise exempted under 40 CFR 257.1) which does not comply with the RCRA Criteria. Such a facility is deemed to pose a reasonable probability of adverse effect on public health or the environment. Conversely, a **sanitary landfill** is defined as a facility which so complies with 40 CFR Part 257 and is presumed to pose no reasonable probability of adverse effect.

Even though the topic of this talk is Part 360, I mention the Federal regulations because of their profound influence on New York State thinking. While DEC has not incorporated the term **open dump** into the offical definitions of our revised regulations, Part 360, for both legal and philosophic reasons, has been brought into conformity with every substantive aspect of RCRA. Even the definition of **sanitary landfill** (360.1[c][31]) borrows in a sense from the Federal concept. The term not only means **a facility** where there is an engineered method of land disposal—as it did in the prior version of 360—but also **one which complies with the whole of the regulation.**

```
          SECTION II
NONCOMPLIANCE WITH FEDERAL
         CRITERIA

0  FLOODPLAINS           0  AIR

0  ENDANGERED            0  GASES
     SPECIES
                         0  FIRES
0  SURFACE WATER
                         0  BIRD/AIRCRAFT
0  GROUNDWATER
                         0  ACCESS
0  APPLICATION TO
     FOOD CHAIN CROPS

0  DISEASE
```

**Figure 32**  *R.C.R.A. Criteria, 40 CFR Part 257*

Finally, because there seems to be so much confusion about it on the local level, I wish to caution that while a sanitary landfill in the Part 360 sense is also a sanitary landfill in the RCRA sense, the reverse is not necessarily true. New York State regulation is more stringent than the Federal Government's (our groundwater criteria, 6 NYCRR Part 703 are a perfect case in point) and, therefore, compliance on the State level is more difficult to achieve than on the Federal level.

Just in case you're confused right now as to what an open dump is, Figure 33 typifies such a facility. As you can see, solid waste is being directly deposited into surface water in clear violation of both Part 360 (360.8[a][1]) and RCRA (40 CFR Part 257.3-3). In terms of statutory obligations, under Subtitle D of RCRA, an open
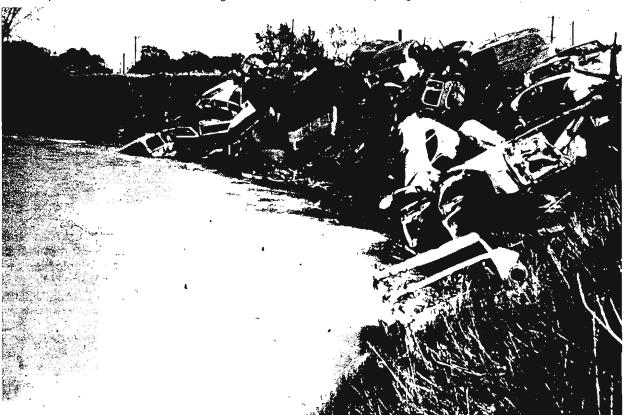


**Figure 33**  *"Open Dumping" of solid waste directly into surface water*

56

dump must either upgrade its performance to Federal standards or close. Failure to do one or the other exposes the site owner to citizen's-suit litigation pursuant to Section 7002 of the Act. Under 6 NYCRR Part 360, every solid waste management facility not otherwise exempted must obtain a permit to operate (360.2), and this can only be achieved if the site meets the design and performance standards of the regulation. Ordinarily operation permits are now issued for a five-year term and are renewable. If a facility cannot meet the minimum standards of 360, or if it is denied a permit after a duly-conducted public hearing, or if it has reached capacity, then it must close in accordance with 360.8(a)(22). Such closure may involve extensive upgrading to mitigate adverse environmental effects.

I've already mentioned that New York State had to revise its regulations to coincide with Federal requirements to end open dumping and upgrade or close open dumps, but there were other important reasons for doing so. our experience in implementing the previous version of Part 360, promulgated in August 1977, clearly showed that there were items which needed amendment or augmentation. One of the most important of these deals with Surety, a provision currently contained in 360.6. The original requirements were expanded (paragraphs B, C and D of 360.6) to secure a form of financial guarantee (ordinarily a performance bond or escrow account) to ensure proper closure of a site; to make certain there is financial accountability in cases where the facility owner and operator are not the same; and to pay for possible claims arising out of injury to persons or property when sudden or non-sudden accidents occur at a facility.

In the case of hazardous waste disposal sites, the Surety provisions may be amended again. Right now, they allow for financial assurances to effect closure and to provide for post-closure monitoring for a period of up to thirty years. For mixed municipal waste landfills, where a lower level of risk is assumed, financial guarantees for monitoring and maintenance are ordinarily required for five years after closure (360.8[b][1][x]); in at least one case, however, a twenty-year guarantee has been negotiated through permit stipulation between the Applicant and the Department.

Now that I've given a bit of historical background, it is time to talk about some individual facets of revised Part 360. I believe everyone on Long Island is at least somewhat familiar with Part 360.8(b)(1)(i) which specifies that a **vertical separation exceeding five feet (5') shall be maintained between solid waste and both bedrock and the seasonal high groundwater table.**

Figure 34 shows a cross-section of a facility which did not keep that buffer zone. As you can see, solid waste was deposited directly upon bedrock (in this instance a fractured dolomite) at this moderately-sized landfill in western New York State. Investigation of the site as part of the Open Dump Inventory detected leachate migration to the groundwater table some thirty to forty feet beneath the fill. While some attenuation (i.e., weakening in concentration) of leachate components was observed, it was generally minor—just as theory dictates for rapid saturated flow through a fractured medium such as the dolomite. in fact, it turned out that
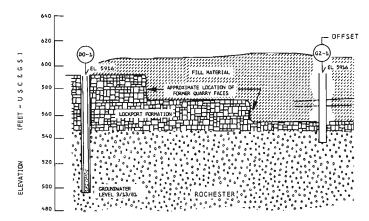


Figure 34    Cross section of a landfill built directly on bedrock in violation of 3608 (b)(1)(i).

this facility ultimately failed the RCRA Groundwater Critera (40 CFR Part 257.3-4) for lead and cadmium and was also in violation of New York State Standards (6NYCRR Part 703) for those constituents and several others as well.

Though an extreme example, it's precisely this type of situation that we in DEC wish to avoid by asking for an unsaturated soil barrier of at least five feet beneath the solid waste. We believe that five feet of a slowly permeable material is the minimum possible thickness (more, of course, is better) which will afford the containment and/or attenuation needed to prevent leachate contamination of the saturated zone.

Another interesting facet of the refuse-groundwater separation requirement is that the term **groundwater** now embraces perched water by inclusion of definition 360.1(c)(16). Perched water has always been addressed in our *State Groundwater Standards, 6 NYCRR Part 703,* and by reference in Part 360 (see 360.8[a][3]), but now the situation is even more straight-forward. When DEC refers to the water table in Part 360, we do not just mean what engineers term the seasonal water table, **but any area of saturation,** be it found in the aerated (unsaturated) or phreatic (saturated) zones.

Actually, there seems to be a great deal of confusion as to what perched groundwater really is. Figure 35, adapted from the *United States Geological Survey's (1977) Groundwater Manual* may help to clarify the concept. A **perched water table** is distinguished from a **true** (also known as seasonal or regional) **water table** in that the former represents a local saturated horizon within a generally unsaturated environment while the latter marks the upper surface of the pervasive zone of full saturation in the soil or bedrock prism. In Figure 35, a perched water table is developed upon a restricted clay layer. The clay is located within the aerated portion of the sand formation, and you can see that the geometry and position of the clay lens has resulted in impounded water at its upper contact with the sand. Presumably, if the retarding clay layer were breached, this water would be free to drain downward through the aerated (unsaturated) soil to the regional water table in the unconfined aquifer. The latter is marked by the static water level (inverted triangle) of the shallow well in Figure 35. Thus, the water atop the clay is literally **perched and hence the** derivation of the term.

**Figure 35** *Schematic representation of Aquifer types showing perched water table*

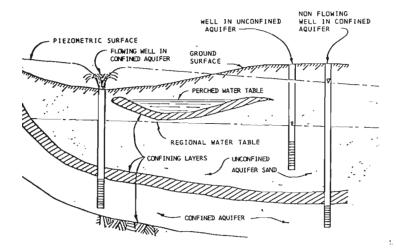Generally, the more impermeable a material you have in the subsurface, the better is the possibility of encountering a perched water condition or high seasonal water table—either of which may violate 360.8(b)(1)(i). This, in fact, makes for interesting landfill siting problems, since impermeable soils are desirable, let us say those with a hydraulic conductivity $K \le 10^{-5}$ centimeters per second (This is also referred to as the **coefficient of permeability**). On the other hand, the high groundwater conditions associated with impermeable soils are not desirable. Wetlands (particularly those in the central lowlands of the State), for instance, frequently mark areas of low-permeability clays but their use as landfill sites is all but precluded under current DEC policy and regulations.

Another Part 360 requirement, very similar in intent to that governing vertical separation distances, relates to liners. Paragraph 360.8(b)(1)(xvii) states that all new sanitary landfills and modications of existing facilities (with modification defined as any lateral expansion of a facility onto a new area, permitted or not, which has not yet received solid waste) will have to be lined by a material which restricts infiltration to that achieved by five feet of soil at a K of $10^{-5}$cm/sec. The facilities must also have leachate collection and storage capability. The rationale for this particular specification derives from both theoretical and empirical studies of the way in which leachate contamination occurs at solid waste disposal facilities.

Table 15 shows that landfill sites in different hydrogeological regimes clearly differ in their susceptibility to leachate-induced contamination of the subsurface. Examining the table, one sees that the degree of endangerment is a function of three basic factors: *unsaturated zone thickness* (i.e., depth to groundwater); *unsaturated zone permeability; and, saturated zone (aquifer) permeability*. Research indicates that the thicker the unsaturated zone, the less chance there is that occult leachate infiltration will result in groundwater contamination. However, even a thick, unsaturated zone of greater than ten feet, if it has a moderate to high permeability, will fail to protect the water resource if there are significant contaminant loadings to the subsurface. For landfilling on Long Island, the implications of Table 15 are important. The permeability generally of the Upper Glacial Aquifer, the uppermost unconsoliated unit on Long Island, is on the order of $10^{-2}$ to $10^{-3}$cm/sec. Thus, even though one might have a very, very thick separation to the groundwater table (i.e., unsaturated zone thickness) in the Upper Glacial Aquifer, the likelihood of developing a significant contaminant plume at an unlined landfill is considerable. Groundwater studies by the United States Geological Survey, Suffolk County Health Department, DEC and others unfortunately verify the predictive accuracy of Table 15 for the Long Island water resource. Figure 36 illustrates a high priority site. One can see both cross-bedding and regular stratified bedding in the fine-textured glaciolacustrine sand. The permeability of this soil is approximately $10^{-3}$cm/sec. At an unlined landfill located in this hydrogeologic setting, one would expect to find groundwater contamination.

## TABLE 15
## Landfill Ranking Hydrogeologic Setting

| Saturated Zone Permeability (cm/sec) | Unsaturated Zone Thickness (m) | Unsaturated Zone Permeability (cm/sec) | Monitoring Priority |
|---|---|---|---|
| >$10^{-4}$ | <1 | NA | High |
| | 1-3 | >$10^{-4}$ | High |
| | | $10^{-4}$-$10^{-6}$ | Medium |
| | | <$10^{-6}$ | Low |
| | 3-10 | >$10^{-4}$ | High |
| | | $10^{-4}$-$10^{-6}$ | Medium |
| | | <$10^{-6}$ | Low |
| | >10 | >$10^{-2}$ | High |
| | | $10^{-2}$-$10^{-4}$ | Medium |
| | | <$10^{-4}$ | Low |

NA = Not Applicable

58

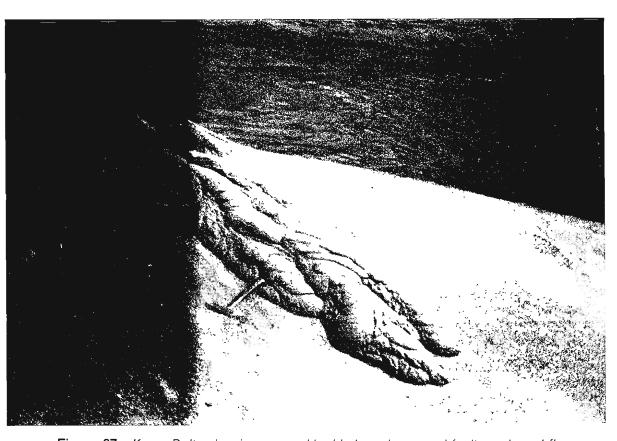Figure 36   *Stratified sands and gravels*



Figure 37   *Kame Delta showing crossed-bedded sands, normal faults and sand flows*

The plume, however, would probably be irregular in geometry owing to the anisotropy of the stratified deposit. Zones of greatest pollution would parallel those of greatest permeability. More gravelly material would be invaded perferentially to the finer-textured sands. Pathways of secondary permeability—such as the small normal faults (vertical lineaments) shown in Figure 37—will abet downward migration of leachate at a rate far greater than one would ordinarily predict from the lithology of the bedded deposit. While, ordinarily, vertical permeability is one to two orders of magnitude less than horizontal permeability in a stratified deposit like this, the reverse may be true where joints, faults or other cross-cutting structures exist. Most likely a plume in an aquifer of Figure 36 type would be composed of relatively tabular elements, the main loci of contamination being confined to horizontal **fingers** within the most transmissible layers.

As I mentioned earlier, Part 360(b)(1)(xvii) requires that you line a facility located in permeable soil, and earlier speakers have illustrated what this looks like using Hypalon or other polymeric liners. Figure 38 shows a test pit excavation of glacial clay, a perfect natural liner. The varved deposit, which is associated with a kamic sand higher up in the stratigraphic section, has an in-place permeability probably around $10^{-7}$cm/sec. With just the necessary grading, this clay is a beautiful base for developing a solid waste disposal facility upon. Further, if excavated and re-compacted, it can be used as a liner elsewhere.

Figure 39 illustrates an in-between case in which the natural soil is borderline for use as a liner, but may meet Part 360 specifications with proper engineering. The material is essentially a silty sand, **SM** in the Unified Soil Classification System, with a natural permeability probably somewhat greater than the required $10^{-5}$cm/sec. If field-compacted to 90-95 percent proctor density however, a one-tenth decrease in permeability over in-situ values is likely to be achieved, and thus an **iffy** substrate can be brought into compliance with the regulation.

As you will recall, I mentioned that 360.8(b)(1)(xvii) provides, not only for liners at new or expanded landfills, but also for leachate collection systems. The latter requirement arises out of DEC's desire to minimize surface and subsurface leachate impacts through containment as well as attenuation. If you slow the passage of leachate or other waste fluid through the aerated (unsaturated) soil prism, you are hoping for various mechanisms, such as cation exchange, organic complexation, precipitation or a number of others, to clean up the fluid. This is known as **attenuation.** Experience shows, however, that attenuative mechanisms are used up very easily in the unsaturated zone, and that they are largely ineffective in the saturated zone. Thus, to ensure maximum protection of the water resource, we must minimize the amount of leachate entering the environment by isolating it within the refuse mass—a process known as **containment**—and collecting it through a properly designed collection network. To contain leachate without collecting it, leads to a **bath tub effect** which encourages surface hydraulic release through the landfill cover or subsurface infiltration through the landfill liner.



**Figure 38** *Excavation of varied clays highly suitable for natural landfill liner*

Of course, minimizing the formation of leachate and taking steps to prevent its contamination of water resources is of little avail if solid waste or its degradation products are allowed to enter surface water or groundwater directly. Accordingly, 360.8(a)(1) dictates the refuse shall not be directly deposited in water, and 360.8(a)(3) makes it a violation for leachate to be discharged into a surface water in the absence of a State Pollutant Discharge Elimination System (SPDES) permit. Figure 40 shows what we are trying to prevent. It portrays a small stream which is now almost wholly colored by leachate. The light area in the photo results from iron hydroxide precipitation, caused by reduced iron, in its ferrous form in the leachate, becoming oxidized to ferric iron as it enters an aqueous environment of high dissolved oxygen. Figure 40 represents a typical, but classic violation of 360.8(a)(3) and the surface water criteria of RCRA and, in fact, this particular facility will be listed by USEPA as an Open Dump for this violation, among others, in 1982. Figure 41 illustrates an obvious breach of 360.8(a)(1): solid waste is being used to fill a wet-

Figure 39    *Sandy silt substrate KE 10-5 CM/sec and possibly suitable for liner*



Figure 40    *Iron hydroxide staining of stream affected by leachate*



Figure 41    *Filling of wetlands by solid waste*

land—a surface water/groundwater interface. This facility, like so many others throughout the State, was for economic reasons begun in a wetland during the 1960s. Without vigorous Part 360 enforcement, it would have continued to expand, consuming more and more of that sensitive habitat.

Turning directly to the subject of groundwater contamination, we have a number of criteria in Part 360 that deal directly or indirectly with that issue. Again, we have the same 360.8(a)(3): Leachate shall not contravene New York State Part 703 Groundwater Standards, with the term **contravene** being defined to mean the violation of a maximum contaminant level of a regulated groundwater constituent beyond the solid waste boundary.

How in practice will contravention be determined? It doesn't make sense to stick a well down in the solid waste, find leachate and then say that the facility does not comply. Instead, we seek to monitor what happens immediately beyond the refuse and determine if there has been any pollutant migration laterally within the aquifer. If a highly permeable aquifer, such as the Upper Glacial or Magothy, is involved and significant leachate quantities are invading the saturated zone, lateral plume migration is apt to be rapid—on the order of feet per day. Thus, there is an excellent chance that properly-screened wells will detect it. Figure 42 depicts a typical groundwater monitoring network in a highly permeable aquifer. The discrete shape of the plume in the isotropic formation, and its movement with the groundwater flow, are both readily apparent. In this case, the plume is relatively old, and has had enough time to move the distance from the refuse to discharge at the river. It is also primarily inorganic in nature, rich in cations such as iron and manganese, and, therefore, manifests a higher specific gravity than the surrounding uncontaminated water. As a result, the plume sinks with the aquifer as it moves laterally as shown in Figure 42. Were the plume to be primarily composed of organics, such as that which would be formed by a leaky gasoline tank, for instance, you would tend to have contaminants concentrated at the base of the aerated soil zone near the water table. Many plumes are **split** as the heavier fraction
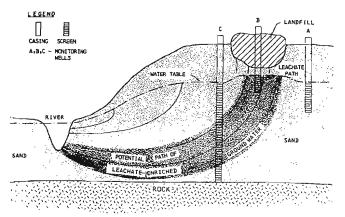
separates from the lighter one. Contaminant velocities in the saturated zone will depend on a number of factors such as hydraulic gradient, aquifer permeability and effective porosity; average travel in a typical environment such as that of Figure 42 might be on the order of about two feet per day.

Illustrating a somewhat more complicated hydrogeologic regime is Figure 43. Here, we have the possibility for contamination not only of the consolidated aquifer, but of the bedrock aquifer beneath it. Regrettably, there are in New York State many cases of multiple aquifer pollution involving soil and bedrock units, and these can be very costly to monitor—not to mention remedy.
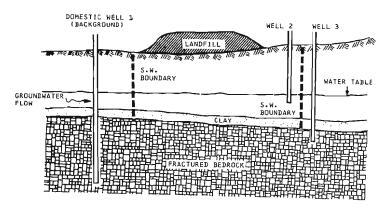


Figure 43    *Monitoring-well layout in more complicated double aquifer situation*

Throughout this talk, I have been referring to contamination, the term used in RCRA, or contravention, the part 360 equivalent, but both words have meaning only in terms of standards. Federal RCRA standards are given in Appendix 1 of 40 CFR Part 257.3-4; New York State's in 6 NYCRR Part 703. The latter differ from the former in being more stringent and comprehensive. For example, the Federal maximum contaminant level (MCL) for lead is 0.05 milligrams per liter, i.e. double the State's allowable 0.025 milligrams per liter. In addition, Part 703 regulates a host of organics which are very important in terms of Long Island aquifer protection that are not addressed by the Federal Government under RCRA, Subtitle D.

Returning to the subject of monitoring, minimum DEC groundwater monitoring requirements are spelled out in 360.8(b)(1)(iii). The paragraph requires that a network of at least three wells, one hydraulically upgradient of the landfill, the other two hydraulically downgradient of it, must be emplaced at a solid waste disposal facility. Obviously, it is simplistic to say that one needs only two downgradient wells and only one for background in the absence of any site-specific knowledge about the landfill. This is why the wording of 360.8(b)(1)(iii) allows the Department discretion to ask for more monitoring installations. In fact, it turns out that, because of geological and practical complexities, most landfills in New York State require more than three wells for proper groundwater surveillance. Figure 44 shows an almost ideal case. The upgradient well is apparent; the down-



Figure 42    *Typical leachate plume and monitoring well layout in sand aquifer*

IDEALIZED THREE-WELL
MONITORING NETWORK FOR
LANDFILL IN ISOTROPIC
AQUIFER.

UPGRADIENT
WELL (BASELINE WATER QUALITY)

OLD
FILL

GROUNDWATER
FLOW

LEACHATE
PLUME

DOWNGRADIENT
WELL NO. 1
(EXHIBITS CONTAMINATION)

DOWNGRADIENT
WELL NO.2
(EXHIBITS BASELINE
WATER QUALITY)

**Figure 44** *Idealized three-well monitoring network for landfill in isotropic aquifer*

gradient wells are staggered, with some closer to the solid waste boundary than others. Sometimes, the difference in contaminant arrival times at the various downgradient wells can be used to compute gross plume velocity. More usually, the staggered arrangement of the wells allows one to see very broadly how plume chemistry varies at different points. Remember, that groundwater moves so slowly in most subsurface environments that it is in a sense like the light emanating from a star. If you are analyzing the tip (distal end) of a plume, you are actually seeing what pollutants 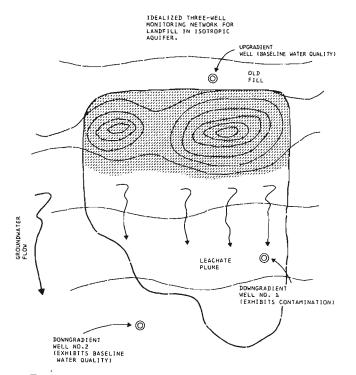were released from the solid waste many years previous. These may not be the same as those generated by the refuse more recently, and present at the proximal portion of the plume. Thus, the properly designed monitoring well layout will permit one to trace a contaminant episode temporally as well as spatially.

If you will recall, Dr. Saar mentioned, in his talk, some of the ways one can diagnose groundwater contamination. Mixed municipal leachate tends to be enriched in certain chemical constituents such as chloride, iron, total dissolved solids, which in some cases can be found in a contaminated aquifer at thousands of times their normal (background) concentrations in the groundwater. Thus, certain constitutents are indices of landfill pollution and can be used to profile the saturated zone near a disposal site. Even when an enforceable regulatory standard is not violated, critical analysis of leachate indicators may alert us to an incipient problem. Table 16 shows the protocol used by DEC during the Open Dump Inventory to test for contamination at over 100 solid waste disposal facilities statewide. Data gathered from hundreds of analyses demonstrates that specific conductivity, which is a measure of total dissolved solids (TDS), is a highly reliable indicator. Temperature, which Dr. Saar did not mention, also happens to be a fine in-

dicator. This is because microbial decomposition in the interior of a landfill produces considerable heat (internal temperatures of 100°F are not uncommon) which can cause a significant temperature rise in an aquifer subject to leachate invasion.

Turning to sampling techniques and frequencies for screening for contamination, these are broadly spelled out in 360.8(b)(1)(iv) and 360.8(b)(1)(v) and in our **Guidelines** to the regulations. Generally accepted methods for sample withdrawal using pumps or bailers are required along with an initial, comprehensive characterization (called **baseline sampling**) of groundwater chemistry using a protocol such as that of Table 16. Routine monitoring complements baseline characterization. It is usually achieved with a limited protocol of leachate indicators at a frequency recommended by the Department. Although for rigorous work, sampling frequency should be determined statistically, based on such things as the likelihood of finding violation of a standard at different levels of probability, this is not always economically feasible. For example, Table 17 demonstrates that, if a contaminent could be expected on statistical grounds not to comply with a given regulatory standard 1 percent of the time (a binomial distribution is used in this case), then, to be 97 percent sure of detecting that violation, one would have to sample 365 times! Obviously, at about $400 per baseline scan, that could turn out to be prohibitively expensive. In practice, applicant monitoring at traditional yearly (baseline scan) and quarterly (routine scan) intervals is usual, and most Part 360 permits are written accordingly.

Although so far in this talk I have concentrated on the hydrogeologic aspects of Part 360, with which as a geologist I am most familiar, the regulation obviously deals with more more than groundwater monitoring or contamination prevention alone. Let me tell you about a few other of its interesting facets: Part 360.8(b)(1)(xix) entitled **Bird Harzards to Aircraft** effectively *bans the siting of any mixed municipal waste landfill (since mixed municipal waste has a putrescible component) within 10,000 feet of an airport runway with turbojet traffic, or within 5,000 feet of one with piston traffic.* Furthermore, existing landfills within those respective distances must show that they do not pose a bird hazard to aircraft as a prerequisite of permit renewal. The inspiration for the bird hazard restriction comes directly from RCRA and the language in 360 is almost verbatim that found in Federal Criteria, 40 CFR Part 257.3-8c. The State merely absorbed the Federal standard. In interpreting this prohibition, it is important to note that as unsettling as a bird strike to an airplane might be—Figure 45 shows what one looks like—such an event does not ipso facto constitute a bird hazard within the meaning of Part 360. To establish that a bird hazard exists, the regulatory agency must prove that the landfill's presence near the airport had a fairly direct relationship to the strike event. This involves a detailed study of the feeding, nesting, and migration habits of the birds within the vicinity of the airport to determine that they a) are in increased numbers as a direct result of the landfill and b) that they are actually the ones involved in the collision. If such an assessment sounds subjective and difficult to make, I can assure you that it is. In fact, it has been our ex-

# TABLE 16

## Analytical Protocol Open Dump Inventory—
## "Project Winter" February-March 1981[1]

| Parameter to be Tested | Federal Standard[2] |
|---|---|
| Arsenic | 0.05 mg/l |
| Barium | 1.0 mg/l |
| Cadmium | 0.01 mg/l |
| Chromium (Total) | 0.05 mg/l |
| Lead | 0.05 mg/l |
| Selenium | 0.01 mg/l |
| Mercury | 0.002 mg/l |
| Silver | 0.05 mg/l |
| Copper | 1.0 mg/l; P |
| Manganese | 0.05 mg/l; P |
| Iron | 0.3 mg/l; P |
| Zinc | 5.0 mg/l; P |
| Total Organic Carbon (TOC) | No Standard |
| Chloride | 250 mg/l; P |
| Fluoride | 1.4-2.4 (Temperature Dependent) |
| Color | 15 Color Units; P |
| Odor | 3 Threshold Units; P |
| Sulfate | 250 mg/l; P |
| Total Dissolved Solids (TDS) | 500 mg/l; P |
| Specific Conductivity | No Standard |
| pH | 6.5-8.5 Standard Units; P |
| Endrin | 0.0002 mg/l |
| Lindane | 0.004 mg/l |
| Methoxychlor | 0.1 mg/l |
| Toxaphene | 0.005 mg/l |
| Chlorophenoxys (2, 4, D) | 0.1 mg/l |
| Chlorophenoxys (Silvex) | 0.01 mg/l |

[1]"Project Winter" effort slated for February 9, 1981 through March 31, 1981 inclusive.

[2]Standards from 40 CFR Part 257; P means standard is proposed in Appendix A of that document.

perience that even the FAA is unclear as to the degree of hazard posed by some of the metropolitan area landfills that agency has been studying for years. This, among other reasons, accounts for the fact that only one of the over 100 landfills investigated by DEC during the Open Dump Inventory was judged to violate this RCRA (and now Part 360) criterion. Taken in this light, the primary usefulness of 360.8(b)(1)(xix) appears to be preventative: It precludes the deployment of future landfills in dangerous proximity to airports.

Remaining on the subject of safety, Part 360 in 360.8(b)(1)(vi) has absorbed another RCRA criterion—this one relating to **explosive gases.** In the case of mixed municipal waste landfills, explosive gases means methane, which ordinarily makes up 45 to 60 percent of all the gases generated at the facility. Generally, 360.8(b)(1)(vi) states that the decomposition gases produced at a sanitary landfill shall not pose a hazard to public health, safety or property. Specifically, it dictates that explosive gases shall not migrate beyond the landfill property boundary in concentrations exceeding their lower explosive limits (LEL for methane is 5 percent by volume). The paragraph also states that explosive gases shall not occur in any facility/structure at concentrations greater than 25 percent of their LEL, or in the case of methane 1.25 percent by volume. Figure 46 is a picture of a large facility in upstate New York with a methane problem. The landfill was located on top of a sequence of porous alluvial soils and filling occurred right up to the boundary. Obviously, there was little impediment to offsite methane migration and an adjoining house located very close to the property boundary was almost blown up as a result. As you can see in Figure 46, a passive venting system was installed in response to the problem, and experience so far shows it to be adequate. Figure 47 shows a relatively simple gas containment system
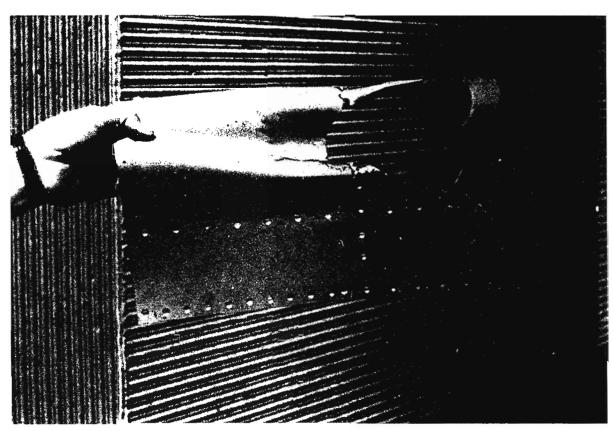
Figure 45    *"Bird Strike" effect on aircraft fuselage*



**Figure 46**    *Capped landfill showing passive venting system and nearby house subject to methane invasion*

# TABLE 17

## Influence of Sampling Frequency on the Probability of Beginning a Water Quality Violation in a Given Year[1]

| Sampling Frequency | Each Sample has a 50% (p[x] = 0.5) Probability of Violating Standard | Each Sample has a 10% (p[x] = 0.9) Probability of Violating Standard | Each Sample has a 1% (p[x] = 0.99) Probability of Violating Standard |
|---|---|---|---|
| Yearly | $1.0-(0.5)^1 = 0.50$ | $1.0-(0.9)^1 = 0.10$ | $1.0-(0.99) = 0.01$ |
| Quarterly | $1.0-(0.5)^4 = 0.94$ | $1.0-(0.9)^4 = 0.34$ | $1.0-(0.99)^4 = 0.039$ |
| Monthly or three (3) years of quarterly sampling | $1.0-(0.5)^{12} = 0.9998$ | $1.0-(0.9)^{12} = 0.718$ | $1.0-(0.99)^{12} = 0.114$ |
| Weekly | $1.0-(0.5)^{52} =$ Essentially 1.00 | $1.0-(0.9)^{52} = 0.996$ | $1.0-(0.99)^{52} = 0.407$ |
| Daily | $1.0-(0.5)^{365} =$ Essentially 1.00 | $1.0-(0.9)^{365} =$ Essentially 1.00 | $1.0-(0.99)^{365} = 0.974$ |

[1]Adapted and enlarged from Sgambat and Stedinger (1981), Groundwater Monitoring Review

Probability of a violation in n samplings $= 1-p(x)^n$ where $p(x)$ is probability of not violating standard in one sampling

which, if it were coupled with active extraction through headers, might serve to upgrade an operating facility with a methane problem or control offsite migration at one after final closure.
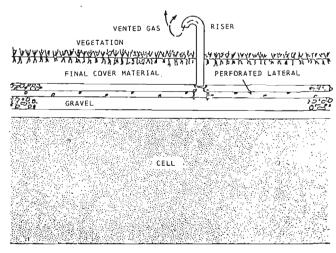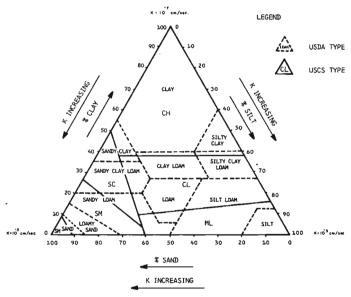


**Figure 47** *Schematic of a very simple passive methane venting system*

Finally, I wish to discuss a particular provision of revised Part 360 which has stirred a great deal of interest at the local government level; the final cover definition of 360.1(c)(13) and the landfill capping requirements. Where a facility is to receive final cover in accordance with 360.8(b)(1)(vii)(e), this must be accomplished using a cap at least 24 inches thick. The upper six inches of the cap must consist of a soil that is suitable to sustain plant growth. The lower portion is to be composed of a material that restricts infiltration as effectively as 18 inches of material of hydraulic conductivity (coefficient of permeability) of $10^{-5}$cm/sec or less if graded at a 2 percent or greater slope. What type

of material might this be? It would most likely be a soil in the clay, silt, clay loam or silt loam fields of the United States Department of Agriculture (USDA) textural triangle. Figure 48 illustrates these fields and the approximate hydraulic conductivity values of the end members. As you can see, the loam fields are large and encompass a number of fine grained soil types, almost any of which will meet the $10^{-5}$cm/sec permeability requirement if compacted to 90-95 percent of their maximum dry density. Actual values of permeability for a given material depend upon a variety of textural and mineralogic factors. Thus, it is best to establish a reference compaction/permeability curve through laboratory testing before considering any material for possible use as a final cover.



SOILD DESIGNATIONS SUPERIMPOSED ON THE USDA TEXTURAL CLASSIFICATION CHART. (CORRELATIONS ARE ONLY APPROXIMATE.)

**Figure 48** *Unified soil classification system*

66

To illustrate how leachate generation may be affected by the permeability and slope of the landfill cap, I have made a series of trial water balance calculations (using EPA's 1975 methodology) for different final cover factors of permeability and slope. Table 18 shows the results for a landfill receiving an assumed annual precipitation of 40 inches per year. In the worst case, you have a cap consisting of a sandy loam soil of estimated permeability $10^{-2}$cm/sec at the minimum allowable slope of 2 percent (row 1). In this case, you may expect leachate quantities of up to 300,000 gallons per acre per year (G/AC-YR). By merely increasing the slope of the final cap to 7 percent (row 2), estimated leachate quantities decrease by about 50,000 gallons per acre annually. If you switch to a less permeable silt loam ($10^{5}$cm/sec permeability approximately), even at the flat slope of 2 percent, you drop leachate production to 200,000 G/AC-YR; this is about 2/3 of the worst case quantity. Finally, if you go to a best case situation, a 7 percent slope, using low permeability silt loam material, a dramatic annual decrease of over 200,000 gallons per acre is possible. While the calculations of the fourth row of Table 18 are based on a homogeneous layer of uniformly low permeability, even more impressive reduction can be achieved with a layered cap construction. Typically, such construction includes a soil cover underlain by a high permeability gravel blanket (which promotes interstitial runoff) underlain by a very low permeability clay layer which minimizes a vertical infiltration into the refuse mass.

Regardless of what design is ultimately selected, however, the benefits of the cap will be seriously impaired if avenues of secondary permeability—fissures or erosion channels, for example—are allowed to develop in the final cover. Figure 49 illustrates a cap that failed not because of the permeability of the base or its thickness, but because of severe erosion of the slope. At this site over 6 feet of sandy silt was laid down, which would have had an approximate permeability of $10^{-5}$cm/sec. Unfortunately, this sub-base was sloped at far greater than 7 percent and was left unvegetated. Sheet and slope wash, caused primarily by heavy precipitation events, led to severe erosion of the cap. Within a matter of months, gullying was so extreme that the final cover had been completely incised leaving exposed the solid waste below. So much for the impermeability of the sandy silt.

Finally, we come to the matter of **financial assistance**—aid to municipalities in complying with the Part 360 regulations. I have left this story for last, because it is a short one. Environmental Quality Bond Act (EQBA) funds, appropriated initially for $175 million, are broken down into about $169 million for high technology resource recovery systems and about $5 million for landfills. The latter category includes funding for such things as maintenance buildings, transfer stations and equipment, but it does not include monies for monitoring and/or upgrading. At present, the landfill funding is utterly exhausted and no new applications are being taken by



**Figure 49**   *Erosion gully in sideslope of unvegetated silty sand landfill cap*

DEC. I am told there may be some money for source-separation community projects, but I recommend that you call Mr. Robert Henderson of the Bureau of Municipal Waste at (518) 457-2190 to see what the status of this funding currently is. In terms of State aid to localities, to upgrade or close open dumps and to meet the very rigorous Federal and Part 360 regulations, I am afraid we can offer some technical assistance and advice, but we have no money. I am sorry the outlook is not brighter but it would appear that cuts on the Federal level if anything will be deeper in the future, and I do not foresee that funding for these purposes will become available soon.

I wish to thank you very much for allowing me to address you, and I hope that I have clarified some of the more perplexing aspects of DEC's solid waste regulations for landfills.

67

# TABLE 18

## Effects of Final Cover Material Type and Slope
## on Infiltration at a Northeastern Landfill

| Cover Material Type | Approximate Permeability | Slope of Vegetated Cover | Average Runoff Coefficient/ Soil Moisture Storage | Annual Infiltration | Quantity of Leachate Gals./Acre/Year |
|---|---|---|---|---|---|
| Sandy loam soil | $\cong 10^{-2}$cm/sec | flat 2% maximum | 0.071/100 mm | 11.24" (285.37mm) | 306,000 |
| Sandy loam soil | $\cong 10^{-5}$cm/sec | Steep, 7% maximum | 0 15/100 mm | 9 46" (240.19mm) | 258,000 |
| Silt Loam | $\cong 10^{-5}$cm/sec | 2% – 7% Average | 0 20/150 mm | 7.08" (179.87mm) | 193,000 |
| Silt loam | $\cong 10^{-5}$cm/sec | Steep 7% maximum | 0.30/150 mm | 4.39" (111.57mm) | 119,517 |

NOTES:
A. Method of Fenn et al (1975, USEPA 530/SW-168)
B. Assumes vegetated final cover with two feet root zone
C. Assumes annual precipitation of 40.35 inches (1025 mm)
D. Neglects detained seepage time in Potential Evapotranspiration values.

On March 9, 1982, a new version of 6 NYCRR Part 360 superseded the May 5th version discussed in the presentation. Although the regulatory requirements dealing with sanitary landfills are identical in both documents, the numbering of three citations referred to in the text has been altered.

The following gives the old citation and the new one corresponding to it:

| May 5, 1981 Version Citation Given in Talk | | March 9, 1982 Version Equivalent Citation |
|---|---|---|
| 360.1(c)(31) | corresponds to | 360.1(d)(84) |
| 360.8(a)(22) | corresponds to | 360.8(a)(21) |
| 360.1(c)(16) | corresponds to | 360.1(d)(39) |

All other citations referred to in this talk are identical in both versions of 6 NYCRR Part 360.

# The Cost of Refuse Disposal by Landfilling

WILLIAM F. COSULICH

William F. Cosulich Assoc., Woodbury, New York

*ABSTRACT*

*The requirements of the Resource Conservation and Recovery Act and Part 360 have had a significant effect on the cost of refuse disposal by landfilling. The Environmental Protection Agency has developed cost estimates for various landfilling technologies for operations of varying magnitudes. Most of the landfills on Long Island receive at least 300 tons of refuse per day. Given the previously developed unit costs per technology, EPA has projected upgrading costs per landfill size.*

*Long Island is considered a sensitive area because it is a recharge zone for a sole source aquifer and, therefore, the cost of sanitary landfilling is higher there in comparison with the national figures. In March, 1979, the New York State Department of Environmental Conservation leachate attenuation and liner policy was established. The policy imposed the following requirements:*

*1) no new landfills will be approved in hydrogeologic zones I, II, III, IV, and V;*

*2) all extensions of existing landfills in hydrogeologic zones I, II, III, IV and V shall have double liners and two collection systems;*

*3) new landfills or extensions of existing landfills in hydrogeologic zones VI, VII and VIII will require at least a single liner, and*

*4) all existing landfills will require final capping.*

*A 1979 study by the NYSDEC estimated costs for plastic liners, capping and leachate treatment for Nassau and Suffolk landfills. Their value of 30 million dollars to upgrade the Long Island landfills is probably less than half of what the actual present-day cost would be.*

The requirements of RCRA and Part 360 have a significant effect on the cost of refuse disposal by landfilling. The Environmental Impact Statement prepared by EPA for the Resource Conservation and Recovery Act estimated that nationally the cost of bringing landfills into compliance will be five billion dollars per year.

EPA produced this cost by developing unit costs for various landfilling technologies for operations designed to handle ten tons per day, 100 tons per day and 300 tons per day of refuse. The costs of these technologies are shown in Table 19. Most of the landfills on Long Island are 300 tons a day or greater.

Available information relating to a typical operation was utilized to define a model landfill, incorporating a baseline set of landfill technologies. After considering the proposed RCRA guidelines, EPA developed a set of upgrading technologies. Given the previously developed unit costs per technology, EPA projected upgrading costs per landfill size, as shown in Table 20.

In this table, EPA lists all the required technologies, and identifies the costs per ton for three daily landfilling rates and for areas of three degrees of sensitivity. Long Island would be a sensitive area because of its water problems. I just want to show you that for a 300 ton a day operation, EPA comes up with a total incremental cost of $2.30, plus baseline costs of $3.95, for a total of $6.25. When you consider that many of the landfill operations on Long Island run over $10.00 a ton, it's clear that the EPA estimates were low.

By multiplying the upgrading costs per site by the number of landfills in each waste type for each size category, a national projection of implementation costs was developed. As I said before, that was that five billion dollars a year, and most people in the field feel that five billion dollars a year is very low, compared to what it's actually costing.

The cost of sanitary landfilling on Long Island is higher than the national figures, due to the fact that the Island is a recharge zone of a sole source aquifer. In March 1979, a New York State Department of Environmental Conservation leachate attenuation and liner policy was established, which required implementation

# TABLE 19
## Costs of Upgrading Technology

| Technology | Cost/Ton | | |
| --- | --- | --- | --- |
| | 10 TPD | 100 TPD | 300 TPD |
| Shredding | —— | —— | 7.00 |
| Bailing | —— | —— | 5.00 |
| Permeable Daily Cover (on-site source) | 0.60 | 0.30 | 0.20 |
| Permeable Daily Cover (off-site source) | 1.90 | 0.95 | 0.65 |
| Vertical Pipe Vents | 0.90 | 0.45 | 0.40 |
| Perimeter Gravel Trenches | 1.60 | 0.35 | 0.20 |
| Gas Collection | 2.50 | 0.55 | 0.30 |
| Synthetic Liner | 4.00 | 1.90 | 1.65 |
| Leachate Recycling (not including collection) | 0.45 | .0.10 | 0.05 |
| Ditching | 0.15 | .0.04 | 0.02 |
| Final Impermeable Cover (on-site source) | 0.45 | .0.20 | 0.20 |
| Final Impermeable Cover (off-site source) | 3.20 | 1.50 | 1.35 |
| Vertical Impermeable Barrier | 1.30 | 0.30 | 0.15 |
| Dike Construction | 2.40 | 0.55 | 0.30 |
| Impermeable Daily Cover (on-site source) | 0.75 | 0.35 | 0.25 |
| Impermeable Daily Cover (off-site source) | 5.30 | 2.65 | 1.75 |
| Ponding | 0.10 | 0.05 | 0.04 |
| Gas Monitoring | 0.15 | 0.03 | 0.01 |
| Groundwater Water Quality Monitoring | 0.60 | 0.10 | 0.05 |
| Natural Clay Liner (off-site source) | 3.20 | 1.50 | 1.35 |
| Leachate Collection Facilities | 0.95 | 0.40 | 0.30 |
| Leachate Monitoring, Removal & Treatment | 5.80 | 1.10 | 0.50 |
| Final Permeable Cover (on-site source) | 0.40 | 0.15 | 0.15 |
| Final Permeable Cover (off-site source) | 1.30 | 0.60 | 0.55 |
| Revegetation | 0.25 | 0.10 | 0.10 |
| Fire Control | 0.04 | 0.01 | 0.01 |
| Access Control | 0.90 | 0.20 | 0.10 |
| Litter Control | 0.05 | 0.01 | 0.01 |
| Compaction | 1.90 | 0.20 | 0.05 |

on a regional basis. This regional policy follows the 208 Plan recommendations closely and imposes the following rquirements:

- *No new landfills will be approved in hydrogeologic zones I, II, III, IV and V.*
- *All extensions of existing landfills in hydrogeologic zones I, II, III, IV and V shall have double liners and two collection systems (Extensions defined as 5 acres or 50% of the existing area.)*
- *New landfills or extensions of existing landfills in hydrogeologic zones VI, VII and VIII will require at least a single liner.*
- *All existing landfills will require final capping.*

The cost of landfill liners, capping and leachate treatment are quite site specific. However in order to develop some generalized costs, a typical 100 foot depth landfill was selected for analysis. Recent unit costs in Smithtown were used to develop liner costs. Since Smithtown used school-age summer labor to place the liners, the Smithtown costs were adjusted upwards to reflect installation at normal labor costs. Leachate treatment costs were taken from a recent study by the Town of Brookhaven.

The costs developed by this study are shown in Table 21. They're listed as both the cost per ton and the cost per acre. We use plastic liners as a reference case. If you're using clay or bentonite, the liner costs must be adjusted to suit.

In 1979, the New York State Department of Environmental Conservation, Stony Brook Office, undertook a study to determine the costs of providing liners, capping and leachate treatment for Nassau and Suffolk landfills. The results of the study are shown in Table 22. For each town, they estimated what it would cost to add a liner, a cap and leachate collection and treatment, and came up with a total cost.

# TABLE 20

## Impact of Guidelines on Operating Costs of Municipal Solid Waste Landfills (Costs/Ton)

| | Site Condition and Size Categories | | | | | |
| | 10 TPD | | 100 TPD | | 300 TPD | |
| Required Technologies | Sensitive | Non-Sensitive | Sensitive | Non-Sensitive | Sensitive | Non-Sensitive |
|---|---|---|---|---|---|---|
| **Gas Control** | | | | | | |
| Vertical Impermeable Barriers | $1.30 | $1.30 | $0.30 | $0.30 | $0.15 | $0.15 |
| **Leachate Control** | | | | | | |
| Impermeable Daily Cover (off-site source) | 5.30 | 5.30 | 2.65 | 2.65 | 1.75 | 1.75 |
| Dike Construction | 1.20 | -- | 0.28 | -- | 0.15 | -- |
| **Surface Runoff** | | | | | | |
| Ponding | 0.10 | -- | 0.05 | -- | 0.04 | -- |
| Dike Construction | 1.20 | -- | 0.27 | -- | 0.15 | -- |
| **Monitoring** | | | | | | |
| Gas Monitoring | 0.15 | 0.15 | 0.03 | 0.03 | 0.01 | 0.01 |
| Groundwater Quality Monitoring | 0.60 | 0.60 | 0.10 | 0.10 | 0.05 | 0.05 |
| Total Incremental Costs: | $9.85 | $7.35 | $3.68 | $3.08 | $2.30 | $1.96 |
| Baseline Costs | 11.15 | 11.15 | 6.65 | 6.65 | 3.95 | 3.95 |
| Total Post-Guidelines Costs: | $21.00 | $18.50 | $10.33 | $9.73 | $6.25 | $5.91 |
| Percent Increase: | 88% | 66% | 55% | 46% | 58% | 50% |

# TABLE 21
## Upgrading Costs

| Technology | Cost/Ton | Cost/Acre |
|---|---|---|
| Double plastic liners | $1.10 | $87,000 |
| Capping | 0.70 | 52,000 |
| Leachate treatment | 0.65 | 48,000 |

We checked a few of the costs, and found that the recently adjusted Smithtown cost and the Brookhaven cost indicate that the estimates were somewhere less than half of the actual present-day costs. So rather than thirty million dollars to upgrade the Long Island landfills, it probably costs somewhere around eighty million dollars. That's just a rough estimate.

In conclusion, I would like to thank Donald Devine of the Town of Smithtown, Jim Heil of the Town of Brookhaven and Morris Bruckman of DEC for furnishing costs used in this paper.

71

# TABLE 22

## Landfill Upgrading Costs
## (NYSDEC Study)

| Landfill | #Liners | Acres Line | Cap | (1) Liner Cost | (2) Capping Cost | Leachate (3) Collection and Treatment | Total Cost |
|---|---|---|---|---|---|---|---|
| Babylon | 1 | 10 | 68 | $ 342,000 | $1,036,000 | $ 474,500 | $1,852,500 |
| Brookhaven | 1 | 40 | 80 | 520,000 | 1,200,000 | 1,139,000 | 2,860,000 |
| Brookhaven Labs | 2 | 5 | 10 | 100,000 | 152,000 | 345,000 | 597,000 |
| East Hampton (7) Fireplace Road | 2 | 33 | 60 | 1,200,000 | 914,000 | 1,916,200 | 4,030,200 |
| East Hampton (7) Montauk | 2 | 14 | 30 | 560,000 | 457,000 | 1,722,800 | 2,740,000 |
| Hempstead, Merrick | · | · | 40 | · | 610,000 | · | 610,000 |
| Huntington | · | · | 50 | · | 762,000 | · | 762,000 |
| Islip, Hauppauge | 2 | 13 | 60 | 260,000 | 914,000 | 185,000 | 1,360,000 |
| Islip, Sayville | · | · | 25 | · | 381,000 | · | 381,000 |
| N. Hempstead | 1 | 33 | 33 | 1,108,000(4) | 503,000 | · | 1,611,000 |
| Oceanside | · | · | 100 | · | 1,524,000 | · | 1,524,000 |
| Oyster Bay | 2 | 21 | 71 | 1,874,000(4) | 1,080,000 | · | 2,954,000 |
| Riverhead | 2 | 17 | 40.5 | 601,000 | 618,000 | 475,800 | 1,704,000 |
| Shelter Island (5) | · | · | · | · | · | · | · |
| Smithtown | 2 | 17 | 17 | · | · | · | 1,400,000(4) |
| Southampton (7) | 2 | 70 | 100 | 1,900,000 | 1,525,000 | 1,597,500 | 5,022,000 |
| Southold | 2 | 14 | 41 | 539,000 | 625,000 | 310,000 | 1,474,000 |
| Total | | | | (6) $6,022,000 | $12,301,000 | (6) $8,165,800 | $30,882,000 |

Note: All costs approximate, site specific problems may vary costs.
(1) Used PVC and or hypalon
(2) Used bentonite seal
(3) From EPA guidelines (Draft EIS, Proposed Regulations, Guidelines for Landfill Disposal of Solid Waste, March 1979)
(4) Breakdown cost unavailable, includes leachate collection and treatment
(5) Landfill closure rather than liners is being pursued
(6) Total exclude TOB, TNH & Smithtown, since breakdown unavailable
(7) Total Cost for these Towns may not be incurred, since cost is based on site life of 20 and 25 years

## Panel Discussion

Moderator:    Dr. Israel Wilenitz, Long Island Regional Planning Board.

Panel:    Dennis J. Lynch, Commr., Babylon Dept. of Env. Control
Henry G. Salomon, L.A. Salomon & Bro., Inc.
Dr. Charles Staff, Staff Industries
Dr. Robert A. Saar, Geraghty and Miller, Inc.
John DeFilippi, ERM-Northeast
James J. Walsh, SCS Engineers
Terry Schnadelbach, R.T. Schnadelbach Partnership
Dr. William Graner, Charles Velzy Associates
Ellen Bogardus, NYS Energy Office
Dennis J. Wolterding, NYS Dept. of Env. Conservation
William F. Cosulich, W.F. Cosulich Associates

**Dr. Wilenitz:** I would like to ask all of the preceding speakers to come forward and take their seats, so that we can now have a short period of questions and answers.

We'll keep this quite simple. If you have a question to ask, and if you're recognized by the chair, I would like you to state your full name, and name the particular individual on the panel you would like to address, if that is what you want. Otherwise you can address the whole panel.

**Mr. D'Antonio:** William D'Antonio, North Hempstead. In view of the different goals you want to achieve on leachate control, methane collection, methane migration, protection, proper vegetation on the landfill, all the way down the line, would it be more advisable to set laws which specify end results, rather than construction techniques?

I refer to particular specifications with regard to capping with material of a specific permeability, as this morning's example, where that capping requirement may put you in conflict with other desirable goals in terms of vegetation, collection of methane gas or prevention of gas migration.

**Mr. Wolterding:** The answer to your question is, of course, you're right, and Part 360 does that. Perhaps I didn't make it clear enough in my presentation, but we have performance as well as design criteria. For example, methane not to leave the site, no contravention of surface and groundwater standards, these are performance criteria. We believe that some of the design criteria we have included in Part 360 will lead towards the prevention of the violation of performance criteria.

It would be helpful to the State, and not just New York but all of them, if the Federal Government would promulgate in final form its guidelines for the design of solid waste facilities. Draft guidelines came out in '79, 40 CFR, and they were never finalized. The purpose of those guidelines was to try to help people know how to prevent violation of criteria.

Although one could argue that some of the standards promulgated under 360 have been rigorous, there have been some comments made in our public hearings that they were too lenient. Let's talk about PVC, polymeric material. You would decrease permeability, and eliminate infiltration almost completely. To ask that a facility, however, be capped with a total impermeable liner would have produced an economic impact on facilities around the State that was unconscionable. So the regulatory agency is trying to compromise between what is the absolutely possible solution and what is achievable economically.

**Dr. Wilenitz:** The logic appears, therefore, that you satisfy all the criteria, such as permeability and so forth, you can still get a highly polluted leachate. Is that it?

**Mr. Wolterding:** That's why I have my stick, Dr. Wilenitz. We may set limits, but we don't necessarily guarantee that if you follow them, you'll necessarily be in the clear. We believe, and have determined during an extensive public participation review process, that these are state of the art criteria. Many of them have been taken from the literature, recent literature, as promulgated by EPA.

Many of them are becoming applicable to hazardous waste as well. However, nobody can foretell what five or ten years of experience with them will actually show.

Just one last comment on that point. A long time ago, in the late 60's, it was believed that a perfect place to site landfills was in thick sand bodies, because like septic tank fields, they would renovate the leachate, and the analogy between a waste water and leachate was disastrous in terms of engineering. Hopefully we're not making similar disastrous blunders now.

**Dr. Wilenitz:** Do any other members of the panel care to comment? We didn't give you an opportunity to question Dr. Graner or Ms. Bogardus or Mr. Cosulich. They talked about methane recovery, methane venting and cost impact. Surely there must be some questions on those topics.

**A Voice:** On the matter of methane venting, one factor is water. If we are to cap all the landfills and are successful in reducing infiltration, would it then have an impact on methane for the future?

**Ms. Bogardus:** There is that potential. I think you're still going to find there is enough moisture in the landfills, with the existing landfills right now.

In capping, you're merely confining the gas. It's now naturally venting out, and by putting on a cap, you're really leaving less of an avenue for it to go vertically. The gas will then migrate laterally, and that's a problem, too. We're currently investigating methods for enhancing landfills, and preliminary results, using small landfill simulators, indicate that any given landfill environment, any given parcel, probably generatates a certain amount of methane over its lifetime. This is a result of the decomposition process, and adding water accelerates the rate at which gas will be generated. So you're right, without the addition of water, minimizing the application of water, the gas generation rate would smooth out, and probably make recovery less feasible.

**Dr. Graner:** You really can.'t extract more than a certain amount of methane out of a piece of solid waste over its lifetime. What you can do is speed up the rate at which it will generate, optimum moisture content being in the vicinity of sixty percent, as I said in my talk. If one were designing a landfill with the specific intention of generating methane for recovery purposes, one could certainly include a facility for adding some moisture and actually attempt to control the process, even if you plan to place a final cap on it eventually.

**Ms. Bogardus:** I think the final use planned for a facility has an impact on the kind of system that you're going to get involved with. You should have a land use plan, extending say fifteen years out. If you want to control, and perhaps speed up the decomposition process, despite the capping, you must have some means of reinjecting moisture in the fill. That will speed the whole process up so that methane production can be maintained over the fifteen years planning period.

**Mr. Salamalick (phonetic):** I have a question. Does anyone have information on the impact, pros and con, in terms of landfill upgrading, length of degradation time for the garbage and type of leachate that comes from reinjecting moisture?

Mr. Wolterding: I'll say something, and Mr. Walsh can see if he agrees with me. Lysimeter studies have been done by EPA on shredded and baled refuse, which indicate that basically there's a correlation, that leachate increases in proportion to the increase of surface area. Leachate will be produced in higher strengths from shredded material, faster than it will be in normal solid waste; however, the material will also stabilize in a shorter period of time. Baled refuse lysimeter tests show the opposite. The onset of leachate is delayed. Leachate produces its strength over a much longer period of time. You'll get the same amount of pollutant out of the leachate. It's the time of initial reaction and stabilization that varies.

Mr. Walsh: The study done by EPA was set up with baled refuse, unprocessed, and they examined leachate and gas flows and composition. As Mr. Wolterding said, with shredded refuse there was a higher strength leachate initially; however, the decomposition process proceeded more quickly. What this means is that, if you were to design a leachate treatment system, if you deemed it necessary, it might be advantageous for you to shred the refuse. Over the long term, there might be a point at which you could pull out these treatment facilities at an earlier point than would be the case in a conventional landfill.

Mr. Kane: Julian Kane. Very little was said today on resource recovery, but one of our problems is space, that we're running out of space on Long Island, and the quality and quantity of the leachate, etc., is interrelated. Is any further consideration being given by the state towards aiding the local municipalities who are attempting to move towards resource recovery, but who are finding all sorts of problems? We haven't zeroed in on the best techniques available. What is the State doing to help provide guidance and direction to help us get out of the dilemma that we're in?

Dr. Wilenitz: The title of this meeting was the **Design and Construction of Landfills**, not **Resource Recovery**. However, if anybody would like to answer, please do so.
      Next question, sir?

Mr. Flipse: My name is William Flipse, US Geological Survey. My questions regard gas generation and recovery. Does promoting gas generation in a landfill have any other benefit in terms of accelerating the ultimate elimination of waste, and are there any benefits in terms of volume reduction?

Mr. Wolterding: I think that certainly enhancing landfill gas generation and promoting the decomposition process, in general, has worked hand in hand. If you're working with gas generation, you're probably enhancing the decomposition process. That can be done through moisture addition, through the addition of nutrient buffers.
      As far as actual volume reduction is concerned, of course in all landfills, we encounter settlement, but that is only on the order of one to ten percent, at most, so it doesn't have a significant impact.

Mr. Schultz: Bob Schultz. I'm curious as to why solid wastes are not separated and treated separately in landfill situations.

Dr. Wilenitz: Do you mean segregating the solid waste into different kinds and placing them in different sections of the landfills?

Mr. Schultz: Yes.

Mr. Wolterding: In fact, there is a Part 360 addressing different solid waste facilities. It also has statements to the effect that commercial wastes, i.e., non-hazardous, industrial, commercial wastes, may only go to certain designated facilities, and septage and scavenger waste to other designated facilities. Septage and scavenger waste is never mixed with solid waste. It is placed in lagoons, in separate areas. Those lagoon areas have to be lined and the lining requirements are more rigorous. The liner permeability has to be $10^{-7}$, for example, as mentioned in 360, rather than $10^{-5}$ for ordinary landfill areas.
      We absolutely agree with you, that the mixing together of varieties of solid waste is not a good idea. Mixed municipal waste, light commercial waste, all that ordinarily goes in the fill together, but even if it weren't a matter of regulations, it would be poor landfill practice to mix a variety of liquids and solid wastes or wastes which conceivably would have poor compatibly with each other.

Mr. DeFilippi: Let me just add a point. I think you're addressing your question towards the feasibility of separating municipal refuse at the site. That becomes a fairly expensive proposition. If you're going to go through that cost investment, it makes more sense to connect to a resource recovery facility. On the other hand, if you're talking about separation at the source, that becomes an economically viable option.

A Voice: Once leachate reaches groundwater, what percentage do you think tests would show as to what is actually precipitated out, and does it change a half a mile, say, from the landfill? I'm assuming you didn't have the money to put in recovery wells.

Mr. Wolterding: The answer to your question depends upon the waste itself and the components of the leachate. If you have a leachate which contains a great many inorganics, and let us say metals primarily, industrial waste disposal areas that contain heavy metal sludges and very little else, you can anticipate binding of those heavy metals in the unsaturated zone. This is particularly the case if you have a lot of clay material or even organic material, because both organics and clay have high cation exchange capacities and could bind up metals.
      In the saturated zone, experience shows, and also biochemistry shows, that you have pH conditions which are not conducive to the binding of metals. Some metals are more mobile than others. Mercury is more mobile. Lead is supposed to be. Cadmium is supposed to be less mobile. Thus, if you have a pure solution of metals, you would expect that there might be some segregation.
      Now, when you have a mixed municipal waste, what happens, unfortunately, is that components change during the leachate process. Metals, for example, don't only exist in their salt state or solution of salt. They exist frequently in chelated form, bound because of the high percentage of organics in the leachate. In fact, a mixed municipal waste has a terrific amount of organic

material, so that you could not necessarily get any kind of predictable segregation.

One thing has been seen in the literature, however. Hydrocarbons, to a large extent, will tend to remain in the unsaturated zone and at the water table. That is the cap layer between the saturated and unsaturated zones. They will tend to flow laterally.

Inorganics will tend to sink, because of density gradients. If your soil is a porous homogeneous medium, you may get stratification, with the greatest concentration forming at a confining layer.

In fact, when putting in well clusters, you have not only to distribute them horizontally, but you also have to vary their depths, in order to make sure you get stratified samples and get within the plume. It's very difficult. I don't think the current state of knowledge of geochemistry would enable you to predict, in laying out a monitoring network, exactly where to break off.

If you know the geology, Darcy's formula will indicate how fast components will move, and therefore give you some idea where to place wells. If you have a fill that is four years old, for example, and groundwater velocity, according to Darcy's formula is, let's say, 100 feet a year, you're certainly going to place a well 3,000 feet hydrologically down gradient. You would also place it where you would expect the plume might be. If the plume started to form about two years after the waste was in place, you might place your most up gradient well at 200 feet distance, and then you would find out if, in fact, you had a plume at all. You can make those kinds of gross calculations and gross monitoring statements to some extent. You can use geochemical statements in evaluating these things, to see if they make sense.

Mr. Lappano: I want to go back to the capped landfill in Connecticut that Mr. Walsh talked about. I'm curious. What slopes did you use? Did you have any problem growing vegetation on top of it? Have you done any field inspection recently to see what the condition of the liner is?

Mr. Walsh: As far as anchoring is concerned, that was done with a block of soil. The side slopes really weren't that severe. There were problems with installation, but nothing substantial. If the slopes were three to one or four to one, rather than two to one, we might have had real problems.

Yes, there was some problem in getting vegetation to take root. As a matter of fact, they had a severe storm which succeeded in washing away a couple of paths 100 feet long and 120 feet wide. There was not damage to the liner, and the cap material was replaced and vegetation took root. Actually, prior to the storm, there was not enough time for vegetation to take root. They did, as I understand it, have to add fertilizer to get vegetation to take root after the event, and, to date, they have not had a recurrence.

Mr. Bebon: Mike Bebon, Department of Energy. Are the clay liners normally installed by contractors, or can it be done by in-house people, and in either case, does the contractor or the manufacturer offer any sort of warranty to the purchaser?

Mr. Salomon: You asked a two-part question. I guess as far as the first part is concerned, you could see, from the slides that I showed, that installation of a bentonite liner is a relatively simple procedure and can be carried out by any contractor who has the type of equipment that I showed. Also, in our case, at least, we insist on having someone at the site to show the contractor or whoever is doing the work how it's to be done. The warranty on bentonite is a thirty-year warranty, but I should mention, and I did mention, that bentonite is a natural product which has been around some billions of years, and there is no reason in the world why it should not be around for several more million years.

Mr. Darsa: Wayne Darsa, to Mr. Salomon. It was mentioned before that clays crack. Is this true of bentonite?

Mr. Salomon: No, it is not, and the reason it is not true of bentonite is because bentonites are, as I mentioned in my presentation, mixed with soil, and only enough bentonite is mixed with the soil to produce the impermeability desired. I also mentioned that, therefore, the character of the soil is not changed at all. In other words, if the soil will not crack, the bentonite or the addition of bentonite will make no difference.

Mr. Darsa: What happens if the soil does crack, you know, if it's more sandy or if silty soil has to be used and there hasn't been a rainfall in a long time?

Mr. Salomon: Well, of course, there is, some contraction of bentonite if it dries out; however, this is extremely unlikely, particularly under cover. Still, if it does dry out, it will contract to some extent, and as soon as it's wet, it will expand. As a practical matter, if it's in the middle of the Sahara, then that might happen. It's extremely unlikely for bentonite to dry out.

A Voice: Mr. Wolterding, when you looked at the cost of various technologies, you mentioned you couldn't see causing people to cap. To me, from a cost point of view, it's one of the most cost effective.

Mr. Wolterding: I'm sorry. When did I say that?

A Voice: You were talking about capping with synthetic liners. I still think that is one of the most cost effective technologies.

Mr. Wolterding: If someone, an engineer, recommended that you ought to cap with an synthetic liner, the answer would be yes.

From a regulatory perspective, though, mandating that in a regulation would have been untenable, because it would have placed an economic burden on everybody throughout the State, and that's the difference. When you pass a regulation that says that now you shall cap with PVC, it's different from allowing it to be a design or economic decision made on a site specific basis.

A Voice: It actually comes out practically the same cost per ton as leachate treatment, because leachate treatment is not cheap.

Mr. Wolterding: We have all been sitting here thinking of existing landfills and the placement of solid waste with respect to ground water. In fact, landfilling is extensive

76

throughout the State, and has resulted in a number of existing facilities which are in hydraulic contact with the aquifer, some very severely so. Now, when you cap in that situation, you can only expect limited benefit. If you have groundwater intrusion, unless you cut out major sources of recharge within the recharge area, you're not going to get significant lowering of the water table within the refuse. What capping will do, perhaps, is prevent the solid waste above the water table from degrading and adding additional leachate pollutant. Eventually the groundwater will deplete that portion of the refuse which is immersed in it, but you don't get quite the same dramatic difference.

Mr. Newton: David Newton from the Cooperative Extension. I don't know who wants to answer this question, but it deals essentially with what kind of configuration leachate plumes take. We saw some diagrams earlier that showed some nice little plumes with regular shapes. Yet someone else said the plume will separate out, with the heavy metal components falling and the organic components rising.

I read a report on the Babylon plume a while back. It tended to imply it was a rather stable, well-defined plume over a period of time. What is the nature of plumes? Are they going to tend to migrate, go deeper, and how do you feel about this in terms of leachate control?

Mr. Wolterding: I'm going to go to the board to answer that question. What you get in terms of a plume depends on how the plume is generated, and the form and composition of the medium it's generated in.

Let us say the geological formation is a uniform deep sand, similar to much of the upper glacial aquifer on Long Island. Assume we have a landfill, uncapped, unlined, receiving forty-six inches of rainfall a year, with one-third of it going into the groundwater table. You will tend to get a plume rather like the one that you saw in the picture. If there are big, seasonal changes, you will get what is actually a plume composed of a series of pulses. First, rainfall will generate a plume. Then the plume, in effect, will be cut off during the dry period, then another one will grow so that you will have a series of contaminated plumes.

That is the simplest case. Now, let's assume that we have a strongly stratified formation, with clay layers alternating with sand layers. In such a situation, you may get a perched plume lying on a clay lens. You may get movement of one plume above the clay lens, and a deeper plume below it, and, in fact, that has been seen in monitoring. You can, in a sense, get a hydrologically split plume. The sections of the plume may move at different velocities, depending on the permeability of the various layers.

A Voice: Taking the situation we have on Long Island, where you have the upper glacial, unconfined aquifer, and the Gardiner's clay beneath it, what would you say would be a typical velocity for the groundwater plume, let's say, something like Babylon?

What I'm getting to in a roundabout way is that we put these landfills all over the landscape, and now we're going to line what's left of some of them and close out the rest and cap them, and possibly put in a few addi-

tional landfills. However, we've already contaminated the groundwater very badly, maybe past the point where it can be recovered to serve as drinking water again.

Is it feasible to just locate the landfills on existing sites, continue to expand them and have a polluted zone downflow from these as a policy? Is that within the framework of this conference?

Dr. Wilenitz: I was just questioning that. Perhaps we should address other questions.

Mr. Kane: One other illustration. I was wondering if you could comment on where you may have pressure heads preventing the contaminated water from going deeply into the magothy and staying up in the upper glacial, an area where we don't have public water supply.

Mr. Wolterding: The hydrogeologic conditions you describe are precisely those identifying the coastal areas, Zones VI, VII and VIII.

As an aid, we can and do employ pumping to create groundwater gradients which will carry pollutants inward to a site, rather than permit them to flow away from a site. In fact, we have granted a variance to a facility, on the condition that they maintain leachate pumping.

In other words, pure groundwater is going into the facility, as opposed to the movement of pollutants out into the groundwater. It means more wastewater for the applicant to treat, but it's a hydrogeologic barrier which acts effectively.

I also understand the USEPA, in its design of hazardous waste regulations, is giving consideration to hydrologic wells which will produce similar hydrologic barriers, so you get groundwater moving towards a site, rather than contaminated water moving away from it.

Mr. Flipse: William Flipse, US Geological Survey. The report dealing with the Babylon and Islip landfills was a Geological Survey report, with which I'm familiar and, since Dr. Saar is no longer here to discuss it, I will. If you look at the cross section through the center line of a plume, you'll see that the lower portion of the plume is actually lagging behind. To address your question about the different rates of travel, they didn't look at organics, so they didn't see any differentiation in the rate of flow of the plume. Also, based on a calculation of groundwater flow, they said the plume should have traveled much further than it did, and they accounted for that by the fact that there had been some delay in the onset of leachate generation.

Mr. Watson: Dick Watson, Brookhaven. Except for talking about some vertical separation of pollutants, the discussion here all presumes that, if you know how long the groundwater is flowing, you know where the pollutants are going. There are other mechanisms by which things move, and I'm curious about whether anyone here can clarify what has been the presumption in most of the talk, whether someone would care to highlight a few of the things which may move by diffusion, where do we have to watch for them.

Dr. Wilenitz: Does anyone wish to comment on that?

Mr. Wolterding: I want to assure you that there's no desire here to neglect any of the mechanisms which

lead to contamination. Diffusion is a real problem. Mr. Flipse mentioned that in the case of the Babylon-Islip plume. It didn't move as far as you would have expected it; however, other data in the literature have shown, particularly with certain kinds of organics, that they have moved faster than groundwater. Flow calculations would allow precise results of diffusion. I could mention a particular site in New York State, which very much perplexes me. There is a major point source emitting PVC in that location. It is eighty-five feet down to the bedrock, the bedrock is contaminated with what appears to be PVC, and it's definitely coming from the major point source. Darcy calculations barely allow for a time of travel like that, so we have to assume that there must be some diffusion mechanism. I think, as time goes on, we're going to understand diffusion sufficiently so that we can include it in our calculations with confidence, but right now I don't think that it's well enough understood to allow us to set rates on it and have some ideas with regard to regulatory policy.

**Dr. Graner:** I think one has to assume that, whenever you have a plume, whether it be from a landfill or from any other point source, you will always have diffusion. If you look at the periphery of a plume, there's always obviously some zone of diffusion. To monitor it, to isolate it, I think becomes very expensive, as compared to just the ability to define a plume, to start off with. The mechanisms of diffusion are fairly common, and wherever you have a plume, you would have to assume one ultimately has diffusion, whether it be by concentration difference or whatever. You will have diffusion, but I don't think that any of the studies over the years on Long Island have shown any large diffusion characteristics in the type of flows we have seen.

**Mr. Kane:** Julian Kane. Relating to the type of lining necessary for a landfill, has anyone ever considered a different type of liner or a less stringent requirement that could be mandated if a landfill is sited in a region of negative pressure head, where there is no downward flow, but only upward flow? It would make it cheaper and would be a deciding factor in landfill areas.

**Mr. Wolterding:** The answer to the question is that the regulations do not favor, as they're currently written, siting in areas depending on hydrostatic heads. In other words, we favor sites above the water table and containment collections of leachate.

I perhaps did not mention as much as I should have that the 360 regulation has a variance mechanism for any one of its parts. If there's a need for a variance economically and technically, and if the variance will not result in an adverse affect on public health or the environment, then it goes through. However, the Department has the right to go above its regulations and ask for even more in terms of environmental safeguards.

This is always written into the variances provisions, so that if, for instance, you wanted to site a facility below the water table for very good technical and economic reasons, you would have to go through the variance procedure and justify the action extensively. Once that justification was made in an administrative hearing, there would be every possibility that that would be the mechanism achieving what you want.

**Dr. Wilenitz:** Are there any other questions? If not, I'd like to make a few remarks about what we've just heard and what we heard during the rest of the day.

It's very evident from the questioning, and some of the answers, that the great preoccupation here is with groundwater and its protection. I don't think anyone is much worried about methane generation and recovery.

Another aspect of the day's meeting that's been very impressive to me is that there has been an enormous variety of professional disciplines involved in this whole area of landfill design and construction. We talk about hydrogeologic behavior. We talk about geochemical behavior. We talk about microbiology, the breakdown of the solid wastes into methane and leachate, and we talk about the chemical engineering of methane recovery and upgrading of methane to pipeline standards.

We talked about the mechanical engineering of methane venting and leachate collection, and, of course, we talked about the sanitary engineering involved in the treatment of leachate. I can't think offhand of any industry that involves so many different disciplines.

Another thing that has impressed me today, as an engineer, is the interesting optimization problem involved in the matter of capping landfills against leachate generation, and thereby denying the solid waste its moisture, which would thereby reduce its capability of generating methane. Methane is, of course, the economic product you want to derive from landfills. I think that this could lead to very interesting design problems. Particularly in larger landfills.

There were too many other points raised to comment on all in detail. I do want to thank, very heartily indeed, our speakers, who seemed to be very eloquent and patient, and I would like to thank the audience, which was also eloquent and patient.

LONG ISLAND REGIONAL PLANNING BOARD
IMPLEMENTATION 208